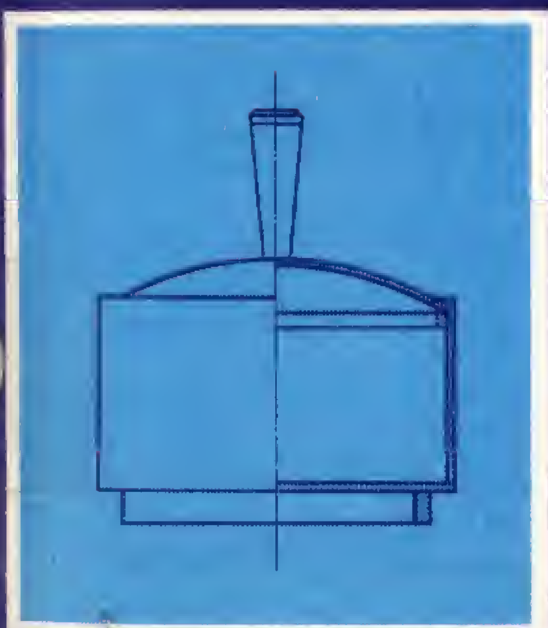
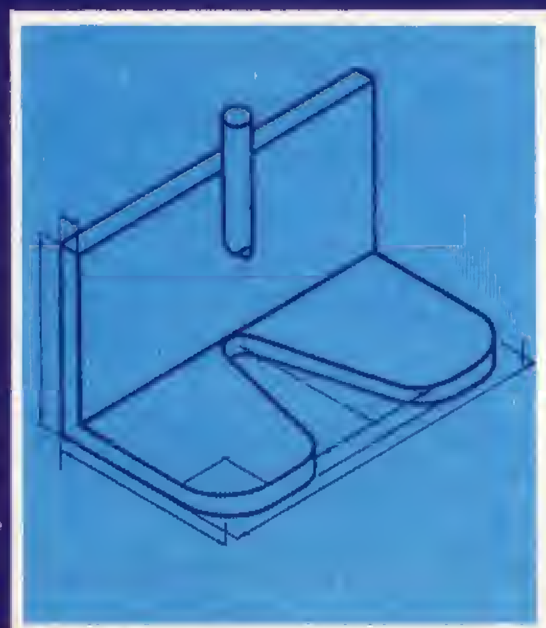
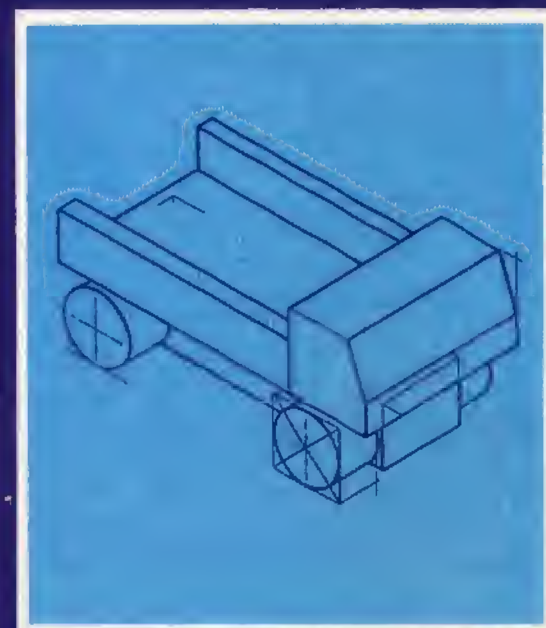
TECHNICAL DRAWING and Design

Gerald Wicks







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Technical Drawing and Design

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HULTON

Preface

In this technological age there is a need for well qualified engineers and scientists, and young people who wish to participate in the fields of engineering and science should appreciate and develop the relevant forms of communication, of which technical drawing is one. The mass media have aroused interests in modern technological achievements, design and "do it yourself", and these all require, to a greater or lesser extent, the facility to understand diagrammatic representations or detailed technical drawings. Ready understanding of them, and of the design and materials involved in their manufacture, enables us to appreciate and become more critically aware of the everyday objects around us.

The material presented in this book and the various areas of interest—basic plane and solid geometry, elementary surveying, and basic design problems in wood and metal—may be considered as a significant part of a young person's fuller general education—it is not a book for the training of professional draughtsmen.

Proficiency in the use of drawing instruments, the development of sound technique and standards of accuracy and neatness are essential for the preparation of good technical drawings. It is important, too, to develop good freehand techniques which may be used for illustrating such material as technology notes, physics experiments and craft projects. The skill required in the use of a pencil is no greater than that necessary for good legible writing.

There are great advantages to be had from a well equipped drawing office where students can use various templates, flexicurves, stencils and transfers for lettering, and consult standard works of reference, such as the abridged editions of BS 308A, BS 1192 and BS 3692, 1967. Opportunity should be given for using a variety of materials, cartridge paper, detail paper, isometric grids, and single sheet Bristol Board for drawings in ink when technical drawing pens may be found more suitable than the traditional ruling pen.

The drawings in this book have been presented in a variety of ways—some in first and some in third angle projection. In others the system of projection has been left for the student to establish. Many drawings in this book are not intended to be fully dimensioned working drawings. Sufficient dimensions are included for a satisfactory solution of the problems, and dimensions not shown are left to the student's discretion. Some drawings are presented which utilize a grid so that dimensions and positions can be determined; some are in isometric projection and the student may take measurements from the drawing in the book.

This book is suitable for all secondary schools preparing for the C.S.E. and G.C.E. examination as well as for non-examination groups, and demonstrates the breadth of the subject and its connection with other curricular activities.

The author wishes to express his thanks to two colleagues, Morris Venables and Geoffrey Hinchliffe, for their help and advice in the reading and checking of the manuscript.

Permission given by the following organizations and individuals to reproduce their original material for certain illustrations and tables in this book is also gratefully acknowledged by the author: Guest, Keen and Nettlefold; Reg Smith; Vyners School.

Contents

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SBN 0 7175 0527 8

First published 1970 by Hulton Educational Publications Ltd., 55/59 Saffron Hill, London E.C.1

Phototypeset and printed in Malta by St. Paul's Press Ltd.

SECTION ONE

Angles

This section deals with angles and their measurement and the many ways in which they may be used.

The following topics will demonstrate what an angle is and establish the size or *magnitude* of the angles of a triangle.

Exercise

Draw a circle of 120 millimetres diameter; draw in a diameter and by repeated bisection divide the semi-circle to form eight equal sectors. (The circle contains four right-angles; the semi-circle contains two, now divided into eight equal parts.) Fig. 1.

On a sheet of tracing or detail paper placed over this *simple protractor*, draw several triangles with the aid of a set square. Mark a point A on the paper and place it over the simple protractor so that A coincides with the centre of the circle. Now draw an angle at A, using the division lines on the protractor; mark another point B on one of these lines, and in a similar manner draw another angle at B. Using this protractor, measure also the angles at C and D. The size of these angles may be recorded inside the triangles and also tabulated in a table similar to the one on the opposite page, Fig. 2.

From the results obtained it will be evident that the sum of the three angles of a triangle is always the same; and that a relationship exists between the *exterior angles*, angles produced by the extension of a side, and the *interior angles* of the triangle.

The exterior angle is equal to the sum of the interior opposite angles: $\angle A + \angle B = \angle D$

Compare also the sides and the angles of a triangle; it will be seen that the largest side is always opposite the largest angle. In a right-angled triangle this side is called the *hypotenuse*: the side opposite the right-angle, the largest angle.

The triangles drawn will probably include these three types:
1. When two sides are equal, two angles are also equal: this is a special type of triangle called an *isosceles triangle*.
2. Where all the sides and all the angles are of different sizes, this type of triangle is called *scalene*.
3. The triangle containing a right-angle: this is called a *right-angled triangle*.

There is also another special triangle and this is called an *equilateral triangle*, with all the sides and all the angles of equal magnitude; a triangle of this type cannot be drawn using a protractor with so few divisions.

It will now be readily appreciated that a protractor with so few divisions has very limited usefulness, and while it has served well for the preceding exercise it must now be replaced by a more detailed divided scale.

Normally a protractor has an accurately divided scale and may contain either four or two right-angles, 360 or 180 *degrees*. They are made in several sizes and the scale of larger protractors are often divided into half degree increments. The degree is the normal unit of angle measurement.

Exercise

Measure the angles of the triangles already drawn in the previous example, using a normal protractor.

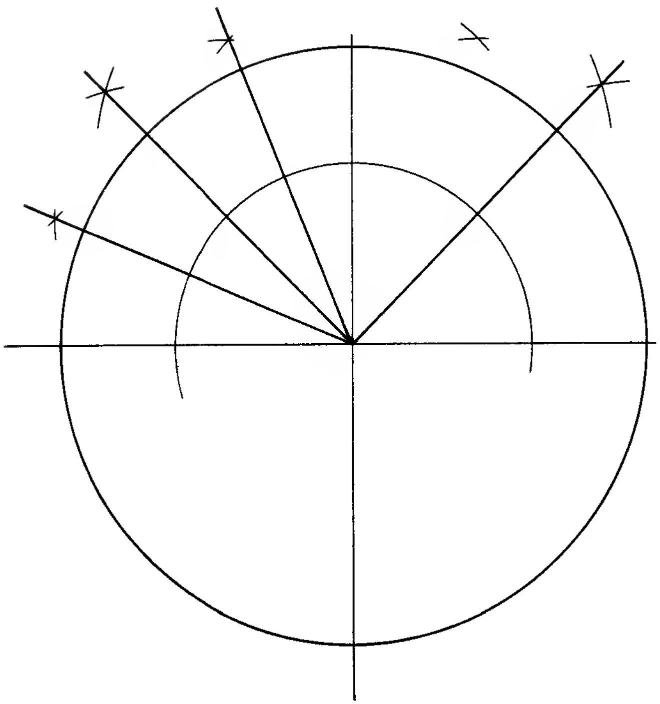
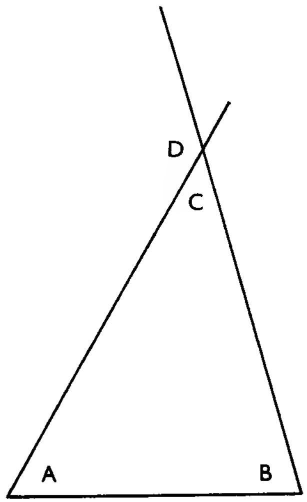


FIG 1



∠A	∠B	∠C	∠D

FIG 2

Angle Measurement

Measurement of angles to determine heights

Angles can be measured by using a *clinometer*. This may easily be made by attaching a protractor, along its base, to a length of wood, and fixing, through the centre of the protractor, a plumb-line, which will show angles of inclination. Fig. 3.

In the appendix is a drawing of a clinometer, using a protractor of suitable size, which can easily be made in a school workshop and works accurately. The protractor turns about its axis and is clamped into position by a piece of 3 mm ply. The protractor is released by pushing the ply away from it with the index finger.

Alternatively, right-angled triangles of different sizes may be made from thin strips of wood. The shortest size of the triangle should never be less than 300 millimetres. Fig. 4.

The method is to sight along the hypotenuse of the triangle, keeping the opposite side of the triangle vertical, until the hypotenuse is in line with the top of the object.

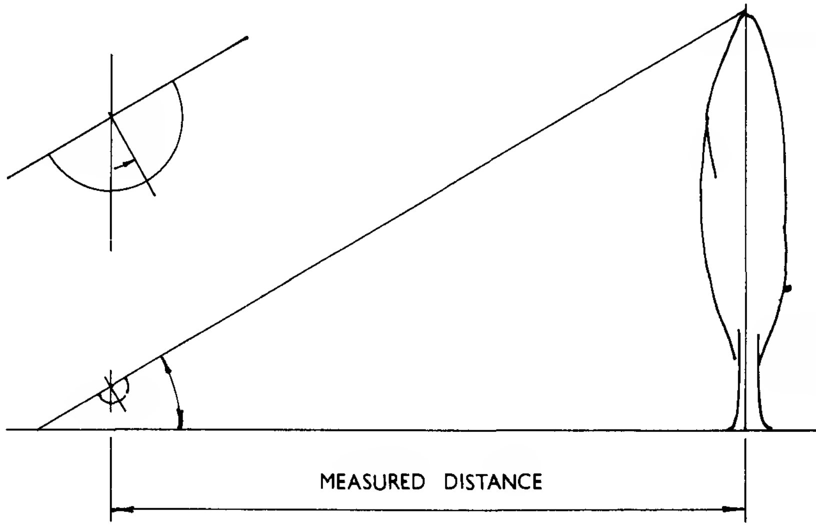


FIG 3

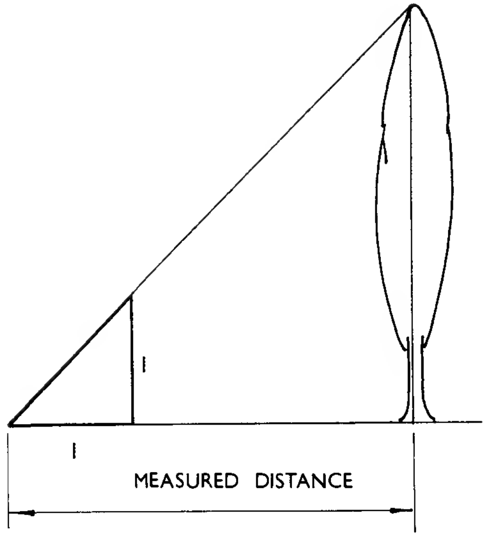
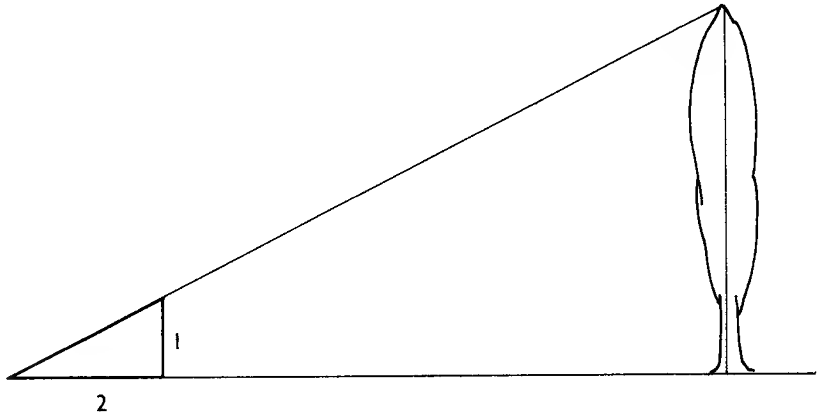


FIG 4



These triangles and the large one containing the tree are similar in shape. Their angles are the same and they are said to be similar triangles.

Exercise

Make an angle-measuring device and with it measure the heights of trees and buildings; there will be plenty of examples around the school.

It will be necessary in these activities to measure the distance from the observer to the object by using a measuring-tape or by pacing the distance.

Having recorded the necessary details, return to the drawing office to draw the triangles and work out the heights of the objects selected.

Simple Scales

It now becomes necessary to prepare a *simple scale*, in order to accommodate these drawings on the sheets of drawing-paper available. The scale chosen should be as large as possible as this will ensure a greater accuracy, and it should be easy to use. These scales may be in imperial or metric units. Two examples are shown, Figs. 5 and 6.

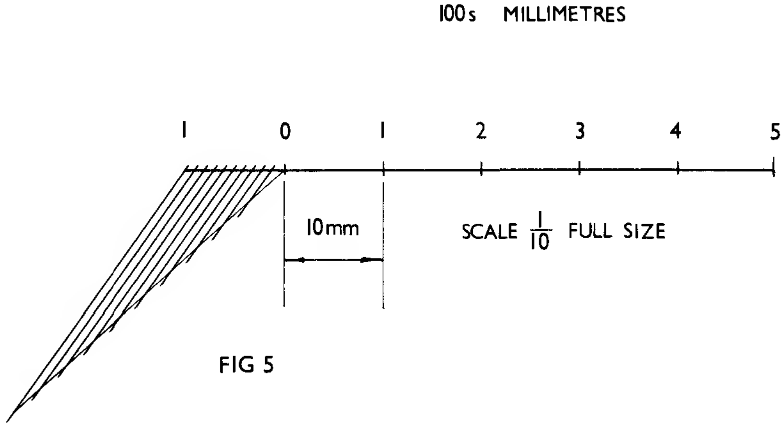


FIG 5

Selecting a suitable scale

Suppose the *angle of elevation* of an elm tree is 40° and the horizontal distance is 25 metres.

If the scale chosen is 10 mm to 2 metres, 25 metres will be represented by a line 125 mm long. This is a suitable scale. If the scale chosen is 10 mm to 1 metre, 25 metres will be represented by a line 250 mm long. This is suitable too.

Exercise

How long a line would be needed to represent a distance of 25 metres if the scale is 1 mm to 50 mm?

Make up some examples for yourself of conversion of lines to easy scales.

Once a suitable scale is chosen, use it to determine, by drawing, the heights of the objects selected. Remember to account for the height above the ground of the observer's eye-level.

By using heights that can be determined by direct measurement, use this fact to compare the accuracy and limitations of the clinometer and triangles. Take the same reading several times.

Is it always necessary to prepare a scale drawing when using the triangles whose sides are in the ratio 1:1 and 1:2? Give reasons for the answer.

It may not be possible to measure the distance to the base of the object chosen. Fig. 7 illustrates the procedure by which it can be calculated.

Take a leaf from one of the trees that was used in the above examples and make a sketch of it or take a leaf print. Write a paragraph about this tree, its type, size and whether it is deciduous or coniferous; also list the uses to which its wood may be put.

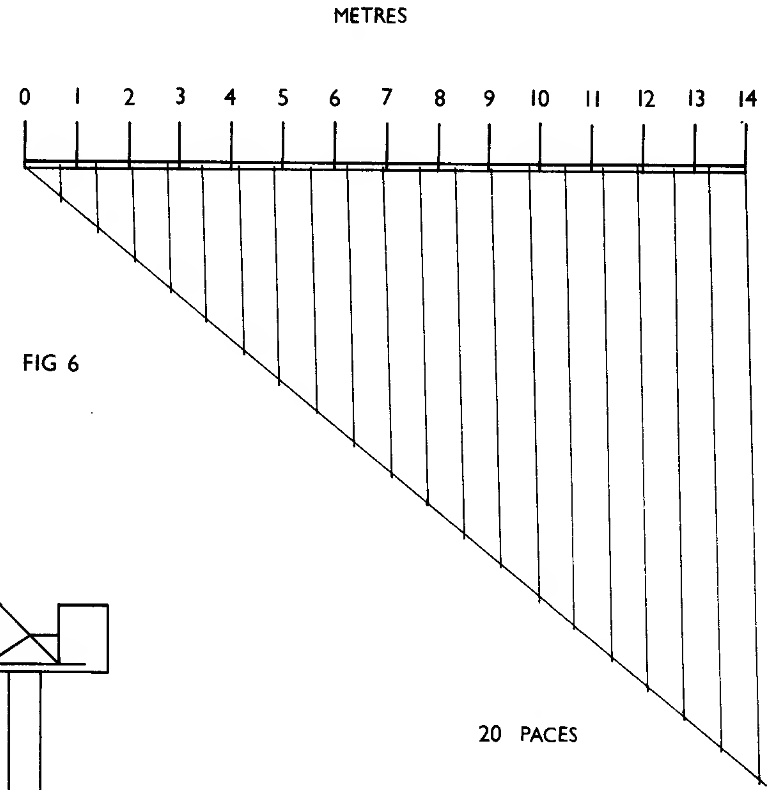

METRES
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
20 PACES

FIG 6

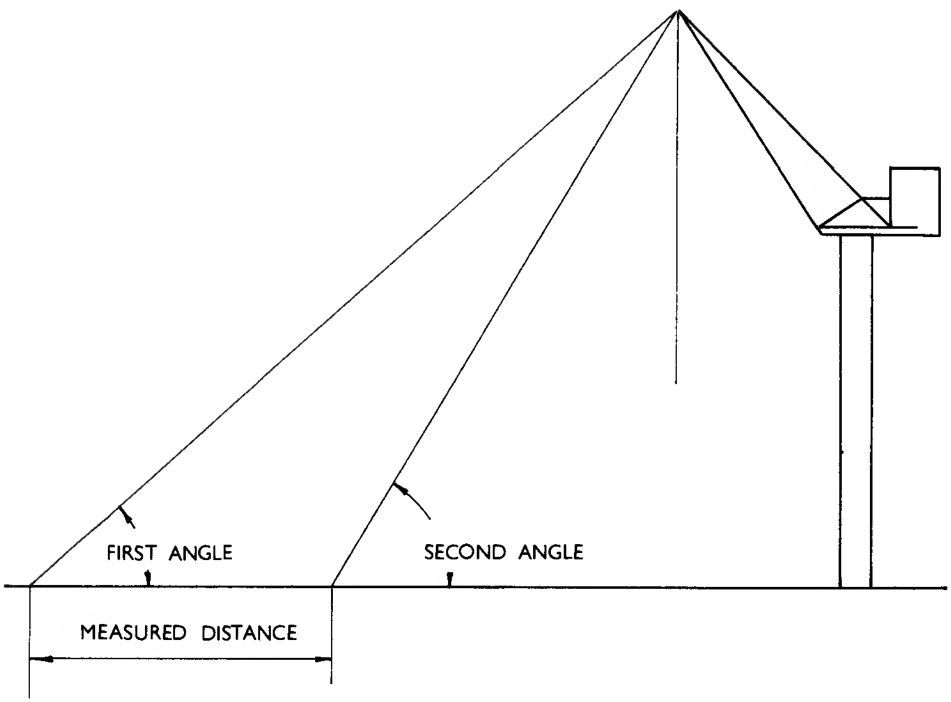

FIRST ANGLE
SECOND ANGLE
MEASURED DISTANCE

FIG 7

Plane-tabling

Radial line method

Plane-tabling is a means whereby field maps or areas may be recorded directly on a sheet of paper on the table, and is an accurate method of mapping small areas. The table, about 750 mm square and mounted on a tripod, is easily produced in a school workshop. It is necessary also to use an *alidade*, a stout boxwood scale with a sighting slot at one end and a wire at the other; when not in use these are folded flat on the instrument itself.

In some ways the most straight-forward way of plane-tabling is by the radial line method, which demonstrates angle measurement very clearly. The plane-table is placed within the area to be mapped and a piece of cartridge paper is attached to it with drafting tape. A *reference* or *polar point* must then be marked on the sheet so that its position represents the table's position within the area to be mapped.

Prominent features within the area, or changes in direction of the boundary, are then selected and if any of the selected points cannot be seen easily from the plane-table they can be marked with a *ranging pole*.

Place the alidade on the plane-table, with the ruling edge on the point previously selected, and use the sights to align it with one of the features chosen. When the alidade is in line, draw a feint line along its ruling edge through the polar point. Measure the distance from the centre of the table to the object. Record this on the table paper along the line representing polar point to the object. Repeat this procedure to record the position of any chosen object within the area. Fig. 8 illustrates the procedure.

Alidades are comparatively inexpensive, but it is easy to improvise one if none is available. Select a piece of hard wood for a straight edge and mount on it a straight length of small bore tube. The tube should be fixed about 40/50 mm above the straight edge for ease of viewing. Glass tube is dangerous, but metal tube may be used if the end is suitably protected.

In the drawing (Fig. 8) illustrating this method, the plane-table has been drawn very large for clarity. It is possible to prepare detailed maps and models using simple techniques such as those already discussed.

The recording of irregular shapes

Should any part of the area be of irregular shape a series of *off-sets* must be used to determine the outline. See Fig. 9. A measuring tape is used as a *base-line* and at intervals along it measurements are taken to the outline. A ranging pole is usually used for the measurements, which must be made at right-angles to the base-line.

Exercise

Within an area adjacent to the school prepare a field map.

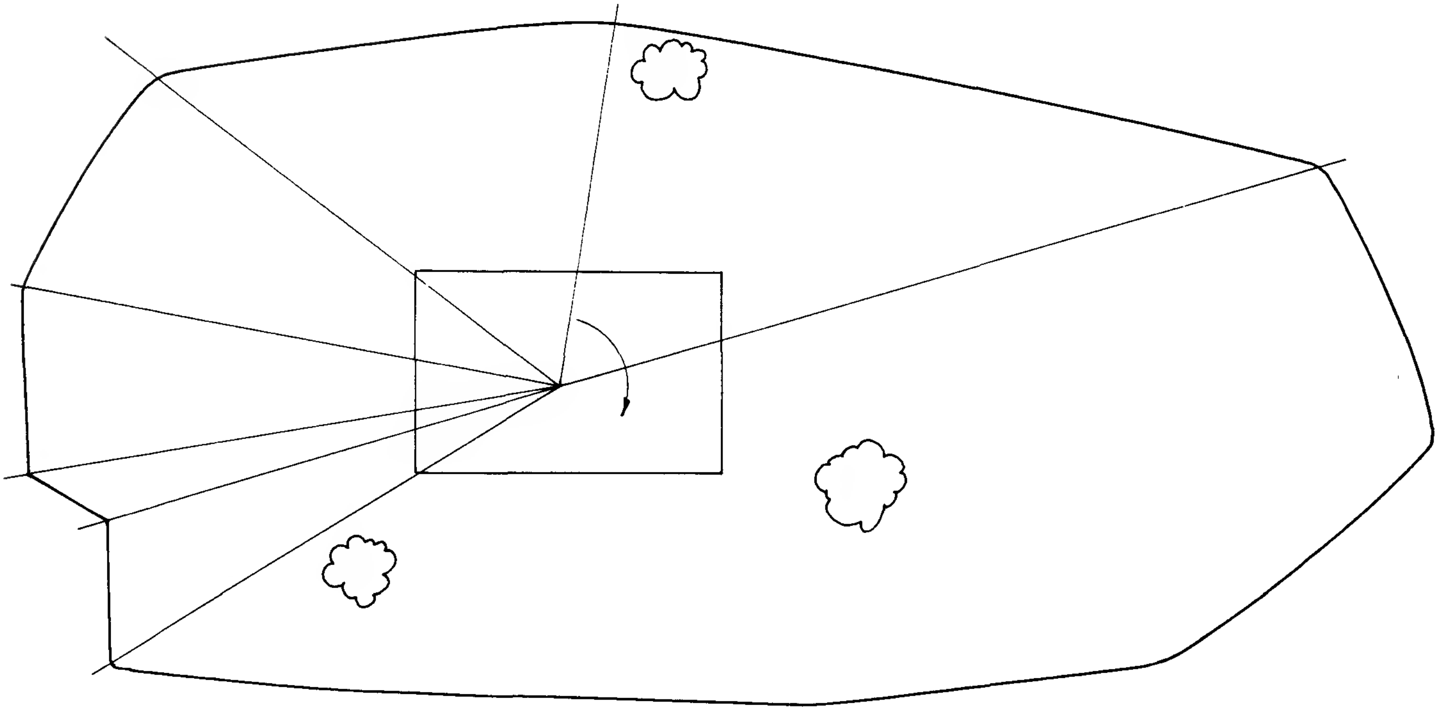


FIG 8

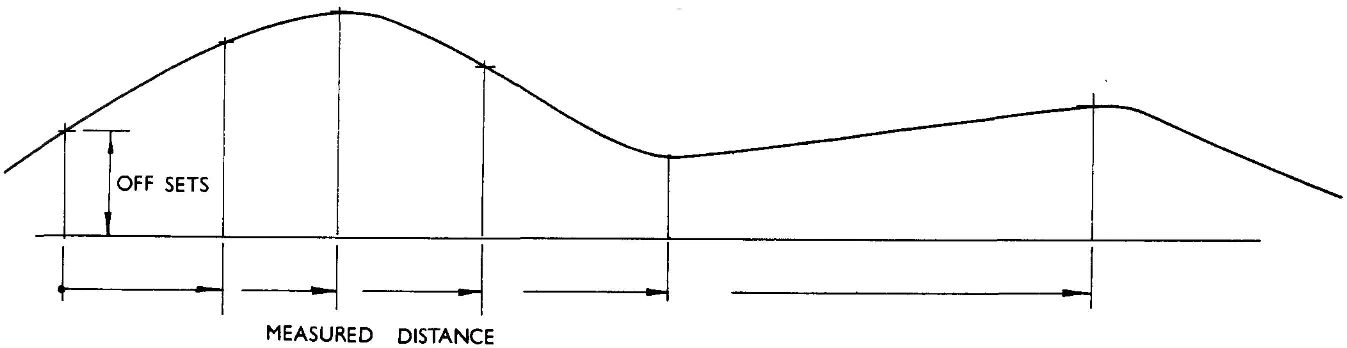
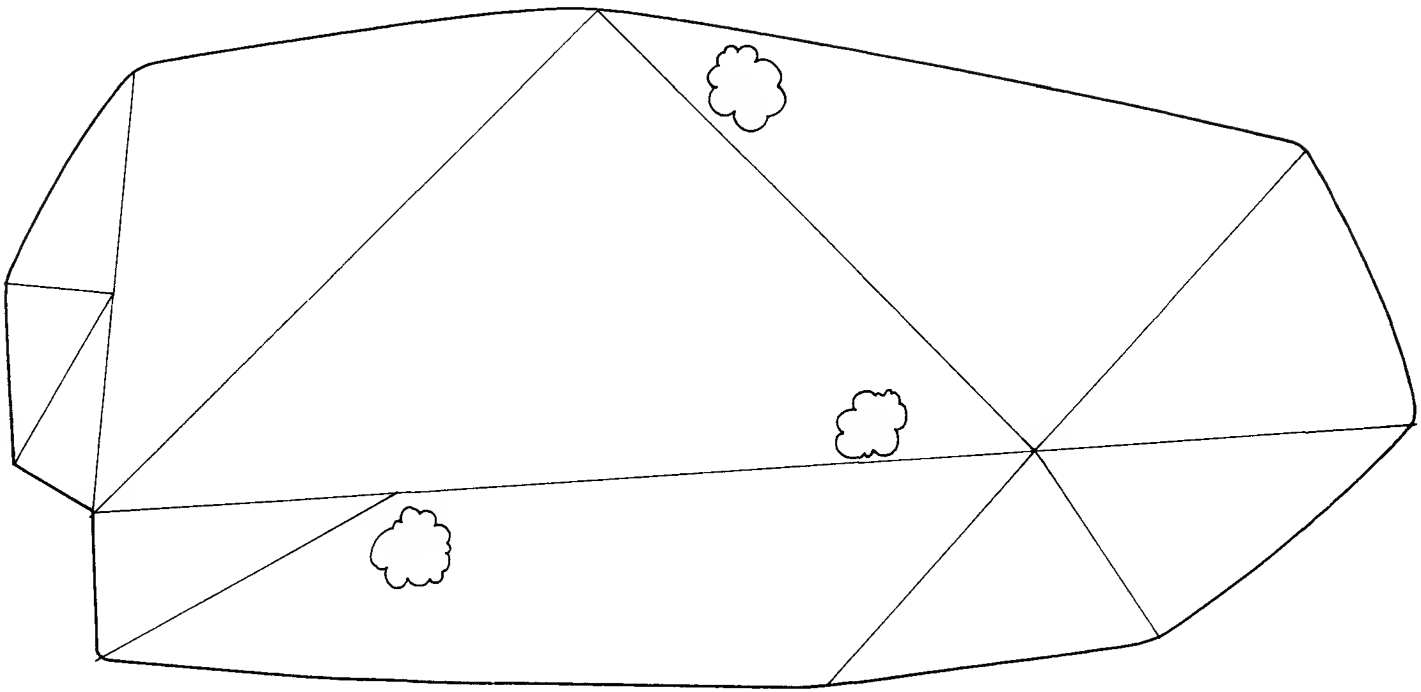


FIG 9

Plane-tabling (continued)

Triangulation

This is an alternative method for surveying a small area. The area is divided into triangles which are measured and then drawn to a suitable scale. It may be necessary, as in the example below, to choose points on one of the main survey lines from which triangles may be constructed. Triangles with sides of greatly differing lengths make for inaccuracy.



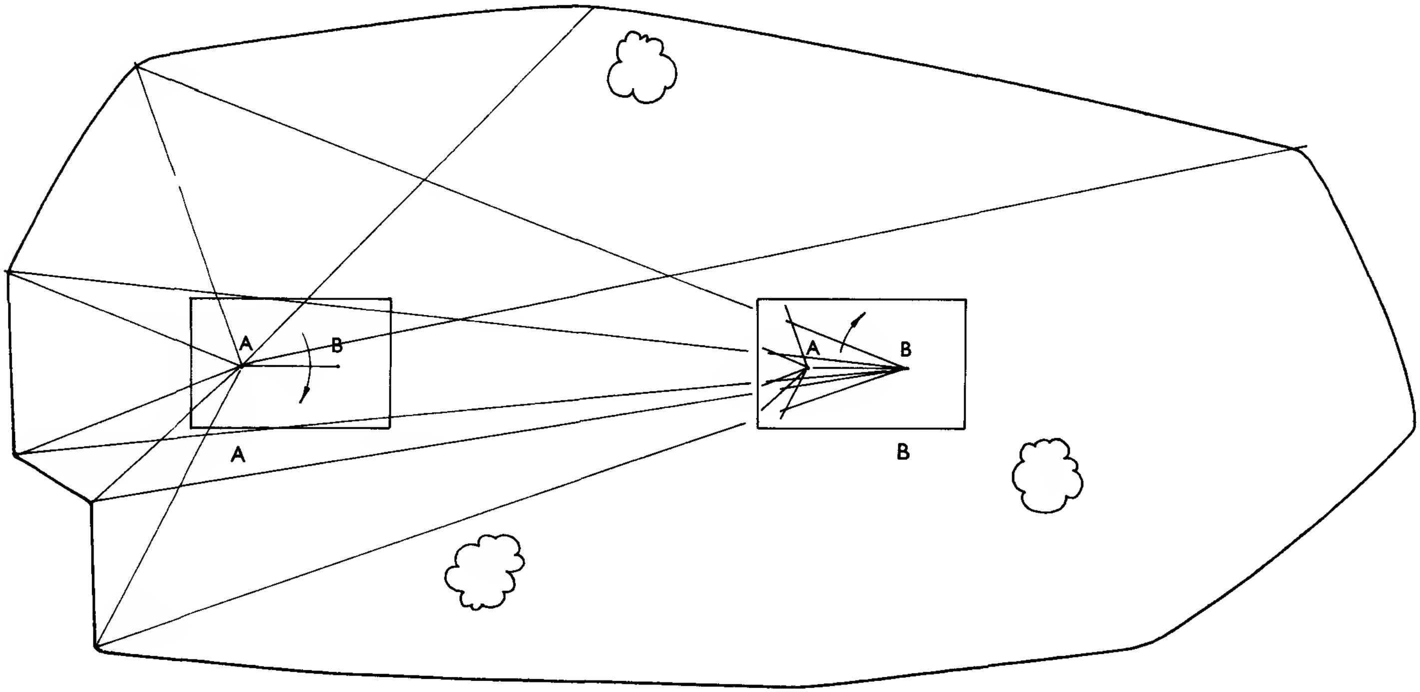
Plane-table

This method is straight-forward in its operation but it requires some planning before starting the survey. This will necessitate a preliminary estimation of the distances to be mapped.

Within the area to be surveyed, choose two positions as far apart as possible, but with an uninterrupted view of each other, from which all prominent features can easily be seen. Call these positions *A* and *B*. The distance between them should be one easily reduced to scale. Set up the plane-table on *station A* and a ranging pole on *station B*. Use the alidade to sight the pole and draw in a base line to scale. This scale must be carefully chosen to ensure that the whole area can be accommodated on the sheet of paper.

Having drawn the base line, use the alidade again to draw a series of radial lines from *A* to all the salient points and note on each line its feature: tree, gate-post, etc. Having done all this at station *A*, move the plane-table to *B*, and with the alidade placed along the base line sight back to *A* and *ensure that the base line is in its correct relative position*. Proceed as before, sighting the same features from *B*. The intersections of the corresponding radial lines will *fix* the selected points. Considerable care must be exercised if accurate maps and plans are to be drawn using this method.

It will be readily appreciated that much useful group topic work can be undertaken with a small amount of equipment and some imagination.



Levelling

This topic, like plane-tabling, may well be linked with work in geography and mathematics; again the pieces of equipment required are simple to make and straight-forward to use.

The drawing, Fig. 10, shows how levelling can be used to record the *profile* of a piece of ground. It can also establish contours. Making the profile of a valley is an excellent exercise in drawing and field work.

At least three people must work together as follows: select two suitable stations a reasonable distance apart. From midway between these two stations, *A* and *B*, a *back-sight* is taken, with a level or simple U tube, on a *graduated pole* placed at the first station *A*, and, in the same way, another reading (called a *fore-sight*) is taken on the second station *B*. The person who was at the station *A* now passes to a third station *C*, beyond the second station *B*. The person taking the levels then positions himself midway between *B* and *C* and takes a back-sight reading on *B*, the second station and a fore-sight reading on the *C* station. These are recorded and so the survey continues. All the stations should be arranged in such a way that they are always in a straight line.

These results—the differences in level—are recorded on a sheet similar to the one shown (Fig. 12), together with the distances between the stations. From these results it is possible to draw an accurate profile to scale. It is normal practice to exaggerate the vertical scale five times: e.g. if the linear scale chosen is 1 mm to the metre, the vertical scale will be 5 mm = 1 metre.

It will be necessary to work in small groups to record, but all can undertake the drawing.

At selected stations on the long valley profile, cross valley sections may be taken. These will be at right-angles to the long valley profile and extend on each side of it.

Both methods require two people of similar height or eye-level. In the first, one person with a level remains on the line of survey and his partner walks up the slope, at right-angles to the main line of survey, until his feet are at his partner's eye-level. The measurements taken are the distance up the slope, that is, the hypotenuse of a right-angled triangle, and the distance risen, which will, of course, be the height of eye of the observer. The person with the level will then walk up the slope to join his partner who in turn climbs further up until once more his feet are visible at his companion's eye-level. This procedure can be repeated as often as necessary. By this method the vertical distances will always be the same, but the distance for this uniform rise will vary with the slope of the ground, the hypotenuse of the triangle.

The second method, using a clinometer, is straight-forward. The person with the clinometer stays on the survey line while his partner walks up the slope measuring the distance. When he turns to face the survey line, the person with the clinometer measures the inclination of the slope by sighting to his partner's eyes and taking an angle reading. In this instance the length of the hypotenuse and the angle of inclination will be recorded. If the slope is complex, several readings will be necessary to obtain an accurate cross valley profile.

The drawings (Fig. 11) illustrate the various methods which may be used, and Fig. 12 shows suitable record sheets.

Suitable levels are shown in the appendix, pages 126–128.

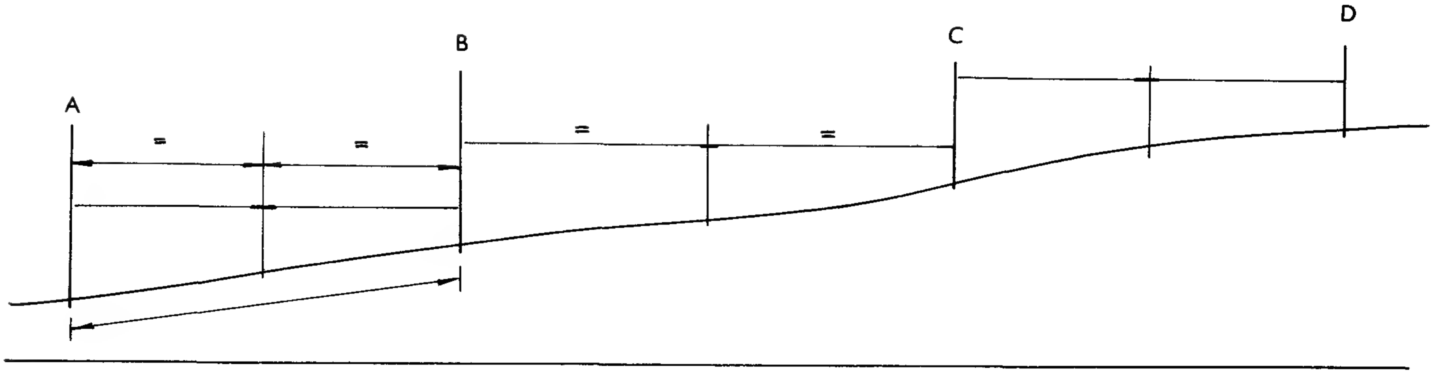


FIG 10

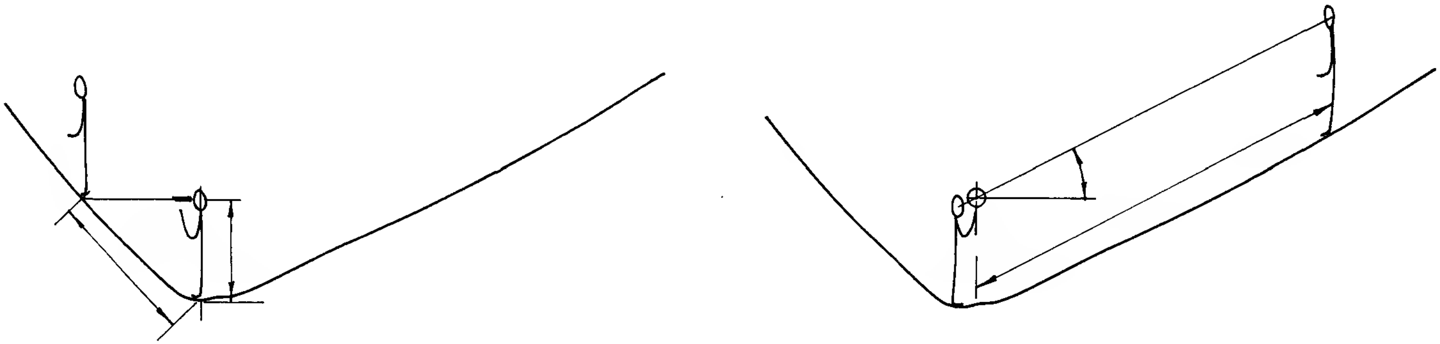


FIG 11

LEVELLING RECORD SHEET

INDICATION OF CROSS SECTION	STATION	BACKSIGHT	FORESIGHT	CHANGE IN LEVEL	REDUCED LEVEL	DISTANCE	REMARKS
	A		——	DATUM LINE		START	
	B		SUBTRACT		(A&B)		
	C						
	D						

FIG 12

VALLEY CROSS SECTION

STATION	HEIGHT CHANGE	INCREASED HEIGHT	DISTANCE	INCREASED DISTANCE
A	AT	——	——	——

Polygons

A polygon is a many sided plane figure. A polygon may be either *regular*, its sides and angles being of equal magnitude, or *irregular*, its sides and angles of varying size.

Consider first the irregular polygon. Use a rule or set-square to draw several polygons, with 4, 5, 6 and 7 sides, and divide each into a series of triangles, similar to those in Fig. 13. Draw up a table with four columns showing:

(*i*) the name of the figure (triangle, quadrilateral, pentagon, etc.);

(*ii*) the number of sides;

(*iii*) the number of triangles contained in the polygon and

(*iv*) the number of right-angles in the polygon. (Each triangle has two right-angles.)

From this table a pattern will emerge. It will be seen that there is a certain relationship between the number of sides of the polygon, the number of triangles and the number of right-angles in it.

Write a sentence to describe the relationship. Try to express this relationship in algebraic terms, using n to represent the number of sides of the polygon.

In a regular polygon each angle is the same size. There are as many interior angles as the polygon has sides. Find each interior angle by dividing the angle sum by the number of sides.

The angle sum of an n sided polygon is $2(n - 2)$ right-angles.

Hence, each angle is $2(n - 2) \div n$ or $\dfrac{2(n-2)}{n}$ right-angles.

Refer back to the table.

The angle sum of a pentagon is $2(5 - 2) = 2 \times 3 = 6$ right-angles.

$$\begin{aligned}\text{Each angle is } \tfrac{6}{5} \text{ right-angles } &= \tfrac{6}{5} \times 90^\circ \\ &= 108^\circ\end{aligned}$$

Each of the interior angles of a pentagon is 108°

Alternatively, a semi-circle whose centre is at one end of the base of the polygon may be drawn and divided, by trial and error, into n parts, that is, 2 right-angles divided into n parts. The angle required will be n parts minus 2 of these parts—that is $\dfrac{2}{n}$ $(n - 2)$. This is clearly shown in Fig. 14.

Having established this angle, the polygon may be drawn. Bisect the sides containing the angle and the intersection of these two bisectors will be the centre of the circumscribing circle. Carefully, and with a feint line, draw in the circumscribing circle and, with a pair of dividers or compasses, mark off the length of the side of the polygon. To reduce inaccuracy, mark some sides in a clockwise and the remaining sides in an anti-clockwise direction. Using lines of good quality, line in the polygon.

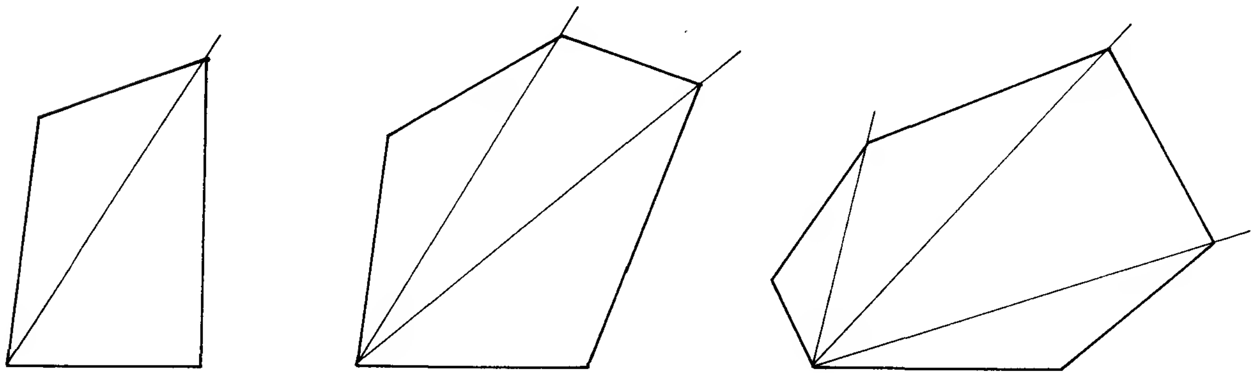


FIG 13

Exercise

Construct a regular pentagon, length of side 40 mm.

Construct either a heptagon, length of side 40 mm, or a regular nonagon, length of side 40 mm.

Draw a circle of 40 mm radius, very lightly, and mark off round the circumference lengths equal to the radius.

How many times is the radius contained in the circumference? With good quality lines, join the intersections of these small arcs with the circle. What is the name of the polygon formed in this way?

Draw a hexagon of 40 mm side, using a 30°/60° set-square manipulated on a tee-square.

In technical drawing, it is often necessary to draw a hexagon, given only the distance across the *flats*. Using a 60° set-square and a tee-square, draw a hexagon given that the distance across the flats (A/F) is 80 mm. Start by drawing two feint vertical parallel lines 80 mm apart, the distance across the flats, and between them a centre line also vertical.

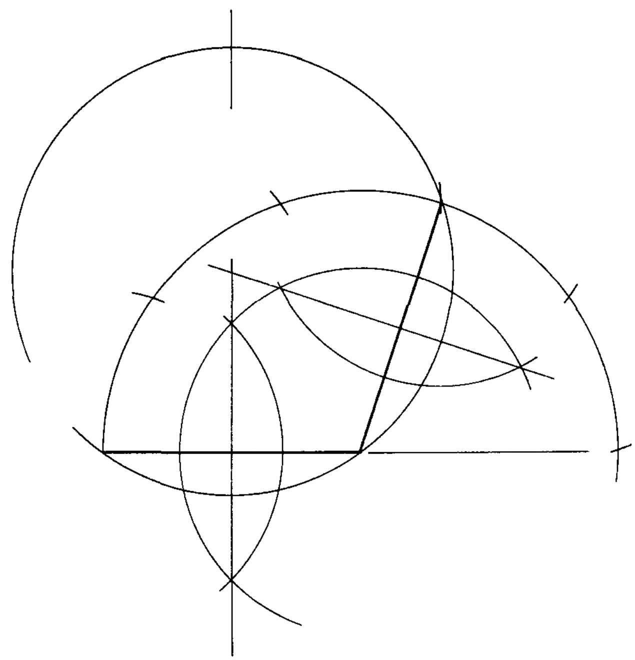


FIG 14

Similar figures

These are figures similar in shape but different in area.

It is often desirable to draw the same item to different scales and there are several ways of doing this without difficulty.

Reduction and enlargement

Suppose a small sketch of the head of a rocking horse (Fig. 15) is to be enlarged, whose full size will be transferred onto the board to be cut. Cover the area containing the sketch with a suitable number of squares, and then divide the area that is to contain the enlarged sketch into the same number of squares. It is then possible to reproduce reasonably accurately the required full size drawing.

Alternatively, a pantograph may be used. This is a jointed frame-work with a tracing and drawing point, simple and very effective in its use. It is also simple to make.

Figures of regular shape can be reduced or enlarged by what may be called the radial line method. From one corner draw a series of radial lines to each corner. Select the degree of enlargement or reduction and then, from this point, draw lines parallel to the sides of the figure and terminated by the radial lines. A partial solution is shown in Fig. 17.

Exercises

Trace the outline of the head of the rocking horse on a piece of tracing paper or detail paper (Fig. 16). Divide the paper into squares of a suitable size and reproduce the outline three times its size.

Having drawn the larger grid and marked on it salient points of the enlarged drawing, remove the paper from the drawing board and line in the head with fair free-hand curves. Move the paper on the board so that the hand is always on the inside of the arc; it is easier to draw a curve in this way, as it exploits the gliding movement natural to the wrist. The wrist is composed of eight bones and is called a gliding joint. One of the bones in the forearm is in fact called the radius.

Make a pantograph using Meccano, thin strips of wood or stout cardboard and establish how it is possible to enlarge and reduce an area *to a specific size*. There may already be a pantograph in school. If there is not, find out what one looks like, from a book. Look up the meaning of the word *pantograph* in a dictionary.

Draw an irregular polygon, similar to the one in Fig. 17, with a base measurement of 60 mm. Enlarge it so that the base is 90 mm. Next reduce it so that the base is half its original length, 30 mm.

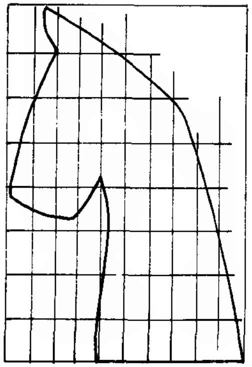


FIG 15

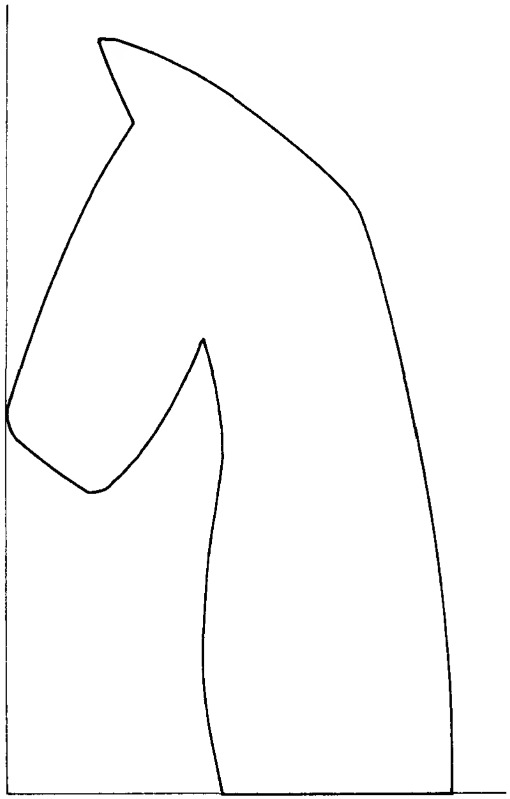


FIG 16

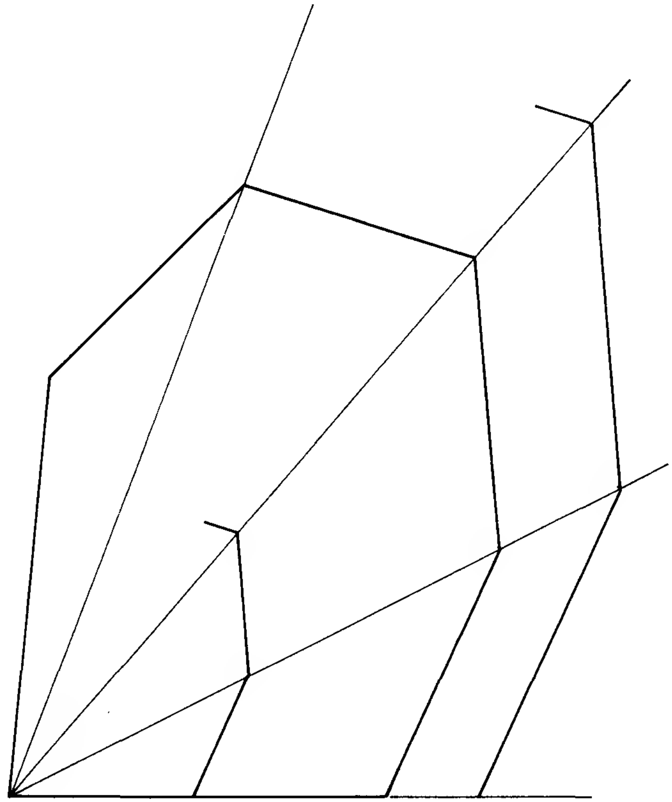


FIG 17

Reduction and enlargement of area

In the foregoing examples consideration has been given to enlargement and reduction of plane figures, but without specific attention to area.

Exercises

Take a thin piece of paper, say A4 or A5 bank paper. Fold it so as to halve both its length and its width. Unfold it and count the number of rectangles. Re-fold, and again halve one side and then the other. Unfold it and count the rectangles. Continue this procedure until the paper becomes too difficult to fold (Fig. 18).

On the piece of paper used for the folding (not in this book) record the results as shown below:

After halving both dimensions ($\frac{1}{2}$ length $\frac{1}{2}$ width) the area was $\frac{1}{4}$ *of the former area*—dimensions $\frac{1}{2}$ (halved) area $\frac{1}{4}$ (quartered).

After halving both dimensions again ($\frac{1}{4}$ original length $\frac{1}{4}$ original width) the area was . . . . . . *of the original area*—dimensions $\frac{1}{4}$ area . . . . . .

After halving both dimensions again (. . . . . .) the area was . . . . . . *of the original area*—dimensions . . . . . . area . . . . . .

After halving both dimensions again (. . . . . .) . . . . . . and so on.

From these results it is possible to deduce that a relationship exists between the ratio of the lengths of corresponding sides of two similar rectangles and the ratio of their areas: the ratio of the areas is equal to the square of the ratio of corresponding sides.

$$\text{Ratio of areas} = (\text{ratio of sides})^2$$

Consider the enlargement of the horse's head in the previous examples (Fig. 16). By how many times has the *area* of this figure increased?

From an irregular polygon (Fig. 17, page 19), whose base dimension was 60 mm, two others were drawn of base dimensions 90 mm and 30 mm. In what ratio has the area of the original figure been increased and reduced?

Consider another equally interesting topic.

Intersecting chords

In a circle of diameter 140 mm (Fig. 19) draw any chord AB. Draw a second chord CD to intersect AB at G. Measure AG, GB, CG and GD.

Find $AG \times GB$ and $CG \times GD$.

What do you notice?

Repeat with another chord EF in the same circle, cutting CD at H. Make sure that CHE is not a right-angle. Again complete $CH \times HD$ and $EH \times HF$. What do you notice now? Make a hypothesis from this evidence, and test it by using another pair of chords in a different circle.

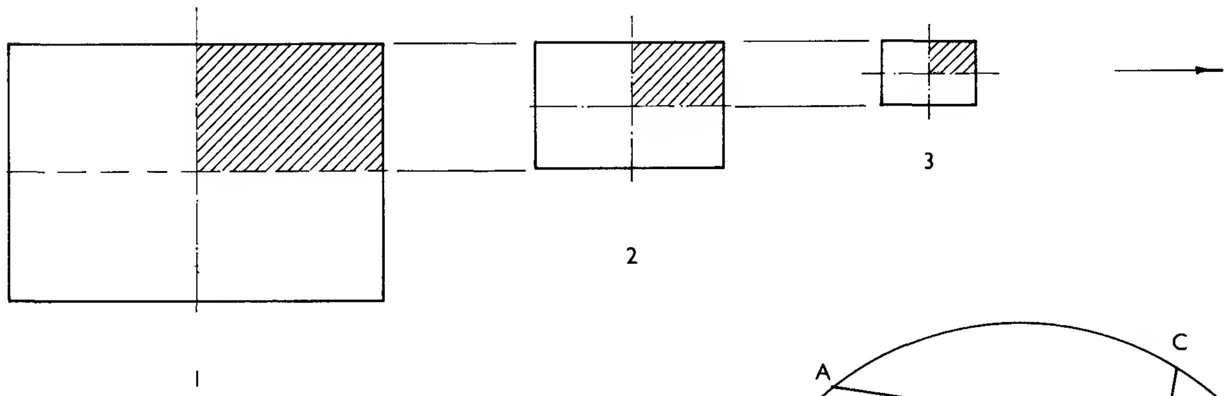


FIG 18

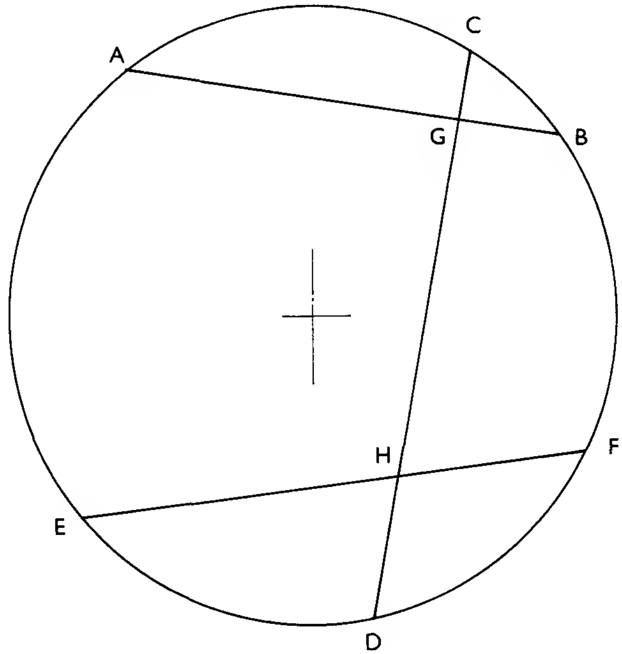


FIG 19

Reduction and enlargement of area (continued)

If a rectangle is to be reduced to a square of equal area, the special case of intersecting chords suggests the solution (Fig. 21).

The sides of the rectangle are a and b (now in a straight line).

Their product will be equal to c^2: a square whose side is c long, that is, $a \times b$ (rectangle) $= c^2$ (square).

The reduction and enlargement of a plane figure to a given area

This is a very straight-forward matter and very interesting as all the relevant important factors have now been established.

1. The ratio of the areas of similar figures is equal to the square of the ratio of corresponding sides. (See page 20).
2. The product of intersecting chords is equal

$a \times b = c \times c$

$ab = c^2$ taking the square root of both sides

$\sqrt{ab} = c$

c is the square root of the product a and b.

Using this fact, the area of a plane figure may be easily reduced and enlarged.

The area of a given figure is to be reduced to half its original area (Fig. 22). Treat the base of the figure, no matter what its length, as *unit* length a. Continue this line half the length of the base b.

$$a \times b = c^2$$
$$1 \times \tfrac{1}{2} = c^2$$
$$c^2 = \tfrac{1}{2}$$
$$c = \sqrt{\tfrac{1}{2}}$$ the length of the new base.

Since the ratio of the area is equal to the square of the ratio of a corresponding side, the new area will be $(\sqrt{\tfrac{1}{2}})^2$, that is, $\tfrac{1}{2}$ the former area.

c is the square-root of the product of a and b. If a is always unit length, b can be *anything*. If b is less than 1, the area will be reduced, and if b is greater than 1 the area will be enlarged.

Exercises

Draw a triangle, base 100 mm, the other two sides 70 and 120 mm. It is a simple matter to reduce a triangle to a rectangle of equal area, since the area of a triangle is the product of the base and half the vertical height.

Reduce this triangle to a rectangle of equal area and then to a square.

Draw an irregular pentagon, base dimension 60 mm, and in three separate drawings, reduce its area by $\tfrac{1}{2}$, $\tfrac{1}{4}$ and $\tfrac{2}{5}$.

With a base dimension of 30 mm, draw an irregular pentagon and construct similar figures whose areas shall be

(i) twice the original area and

(ii) two and a half times the original area.

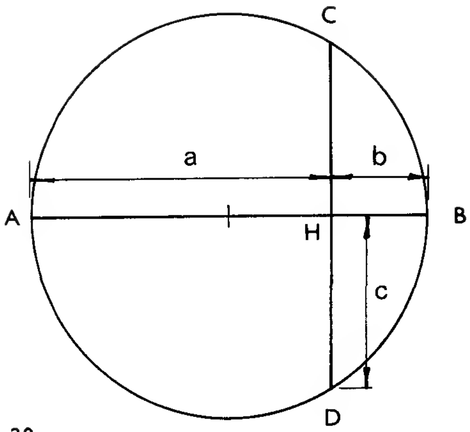


FIG 20

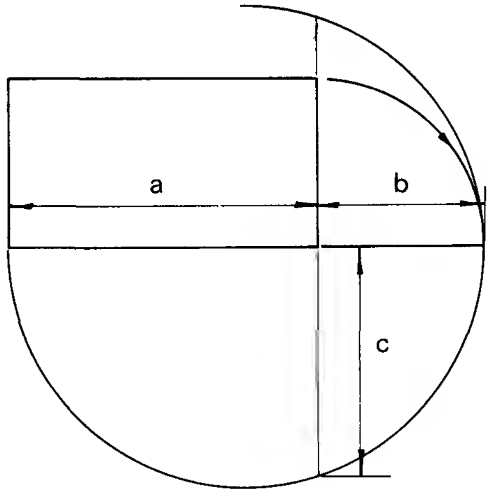


FIG 21

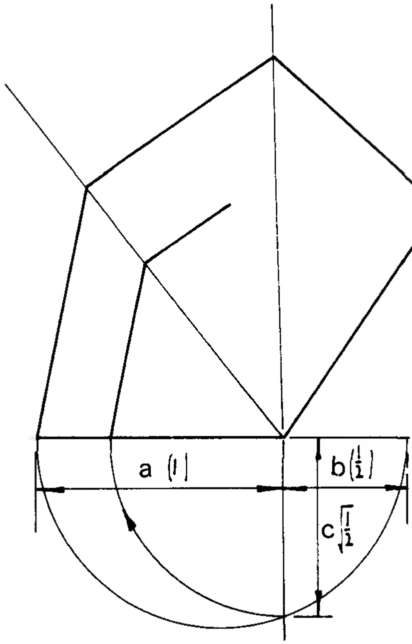


FIG 22

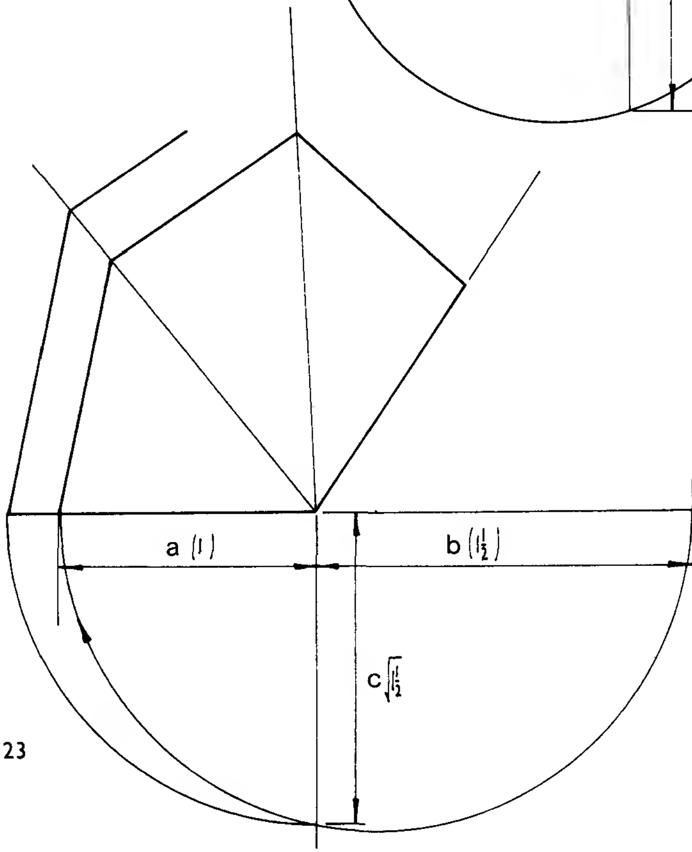


FIG 23

Tangents

A tangent is a line that touches a curve but does not cut it. Often in technical drawing it is necessary to draw a tangent and, so long as the straight line touches the arc, this will be acceptable in many instances.

However, it is sometimes necessary to construct a tangent and certain fundamental facts must be known and used. The major consideration is that at its *point of contact* the *tangent* to the circle *must be at right-angles* (*or normal*) *to the radius of the circle*. The intersection of the radius (produced) and the tangent is called the point of contact, the exact point where the tangent touches the curve.

Exercises

Draw a semi-circle of radius 60 mm; draw in the diameter *AB*. Choose a point *C* on the circumference of the semi-circle. Join *AC* and *CB*. Measure $\angle$ *ACB*. Repeat, using a different point for *C*.

What have all these angles in common?

The knowledge that angles within a semi-circle are right angles enables all tangency problems to be solved. Look at drawing (Fig. 24). Select one triangle and draw it within a semi-circle (Fig. 25). The line *AC* is a tangent to the circle of radius *OC*. The radius *OC* and the tangent from the point *A* form a right-angle. Draw the other two examples shown. The example, Fig. 26, shows a *direct common tangent* and the one next to it, Fig. 27, shows a *transverse common tangent*. The circles are 40 mm and 70 mm in diameter and the centre distance is 80 mm.

Consider first the direct common tangent

In order to reproduce the conditions shown in Fig. 25, the 40 mm diameter circle must be reduced to a point and the radius of the 70 mm diameter circle must be reduced by a corresponding amount, namely 20 mm. Draw a semi-circle whose diameter will be the centre distance of the two circles. The point of contact will be determined where the semi-circle cuts the reduced circle. Draw in the radius and tangent and transfer this tangent to its required position by manipulating two set squares so that it is parallel with the tangent constructed.

The transverse common tangent is treated in the same way: the smaller circle is reduced to a point and the larger circle is also adjusted by a corresponding amount.

A tangent is also the relationship that exists between the opposite and adjacent sides of a right-angled triangle.

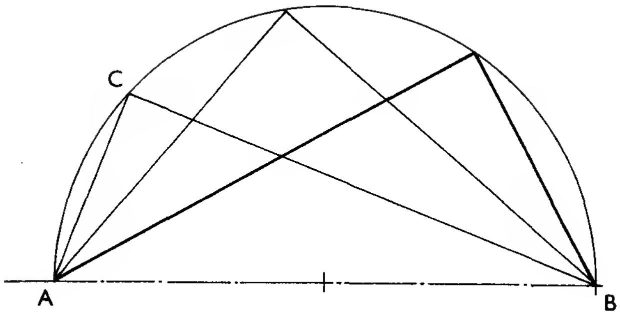


FIG 24

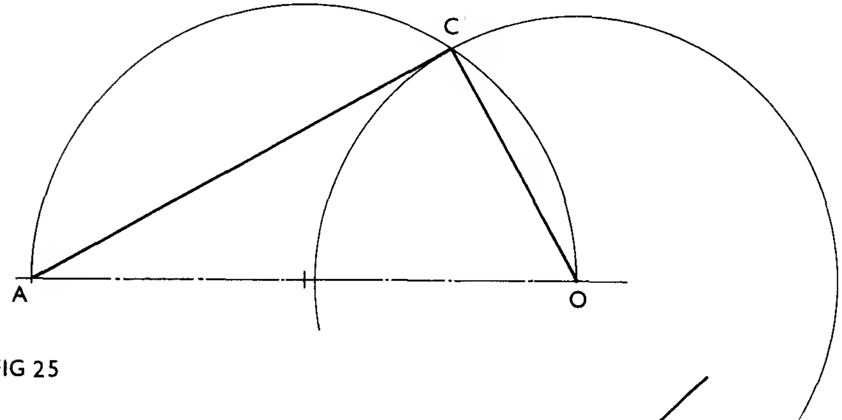


FIG 25

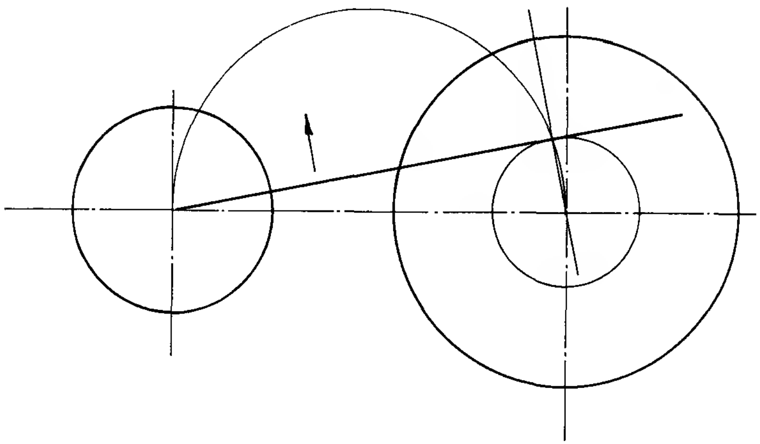


FIG 26

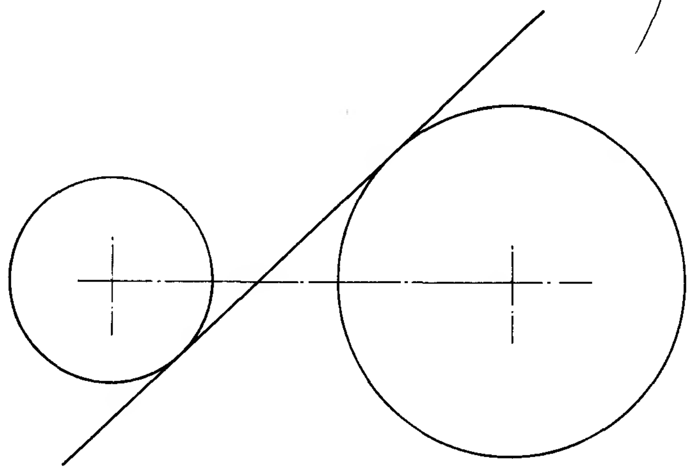


FIG 27

Curves of special interest

Cycloidal Curves

This group of curves is generated by the movement of a disc or circle which rolls without slipping along a straight or curved path.

Cycloid

This is the most simple of the cycloidal curves and is generated as the *locus** of a point on the circumference of a circle which rolls, without slip, along a straight line. A portion of this curve is shown in Fig. 28.

When the circle has made a complete revolution, the point *A*, which was initially in contact with the line and has described one arch of the *cycloid*, will again be in contact with the base line. In drawing, the circle is divided into twelve equal parts using a 60°/30° set-square, and the line, along which the circle rolls, is also divided into twelve equal parts. Although this line represents the circumference of the rolling circle, it is not usual to calculate this distance, as a graphical method will give a satisfactory degree of accuracy. It can be readily seen that when half a revolution is complete, the point *A*, the initial point of contact, will be at its highest point. Intermediate positions may be obtained by drawing part of the circle and marking off the corresponding position of *A*.

**Locus*—A line recording all positions of a point satisfying a given condition.

Exercise

Draw the cycloid generated by a circle 60 mm in diameter.

Epicycloid

An *epicycloid* is the curve generated by a point on the circumference of the rolling circle, when the circle rolls without slip on the *outside* of a circular path.

Hypocycloid

When a circle rolls without slip on the *inside* of a circular path, a point on the circumference of the rolling circle will trace a *hypocycloid*.

Trochoids

This group of curves is similar, in many respects, to the cycloidal curves in that they are formed by the rolling action of a circle along a straight or curved path. However, the point which traces the curve as the disc rolls along is either *inside or outside* the circle. When the point is inside and the disc rolls along a straight line, the curve formed is called an *inferior trochoid*, and when the point is outside it is said to be a *superior trochoid* (Fig. 29).

Exercise

Draw a superior and an inferior trochoid, with a rolling circle 60 mm diameter. For the inferior trochoid use a radius of 20 mm and for the superior trochoid 50 mm. Use a similar method to that used in drawing the cycloid.

How many of the above mentioned curves may be associated with a bicycle as it is pushed along?

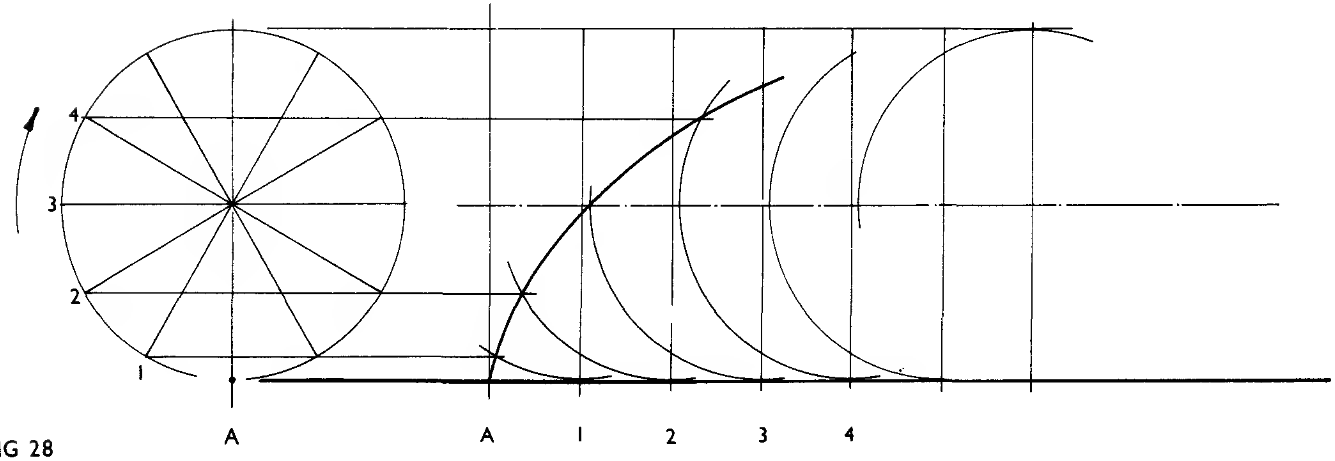


FIG 28

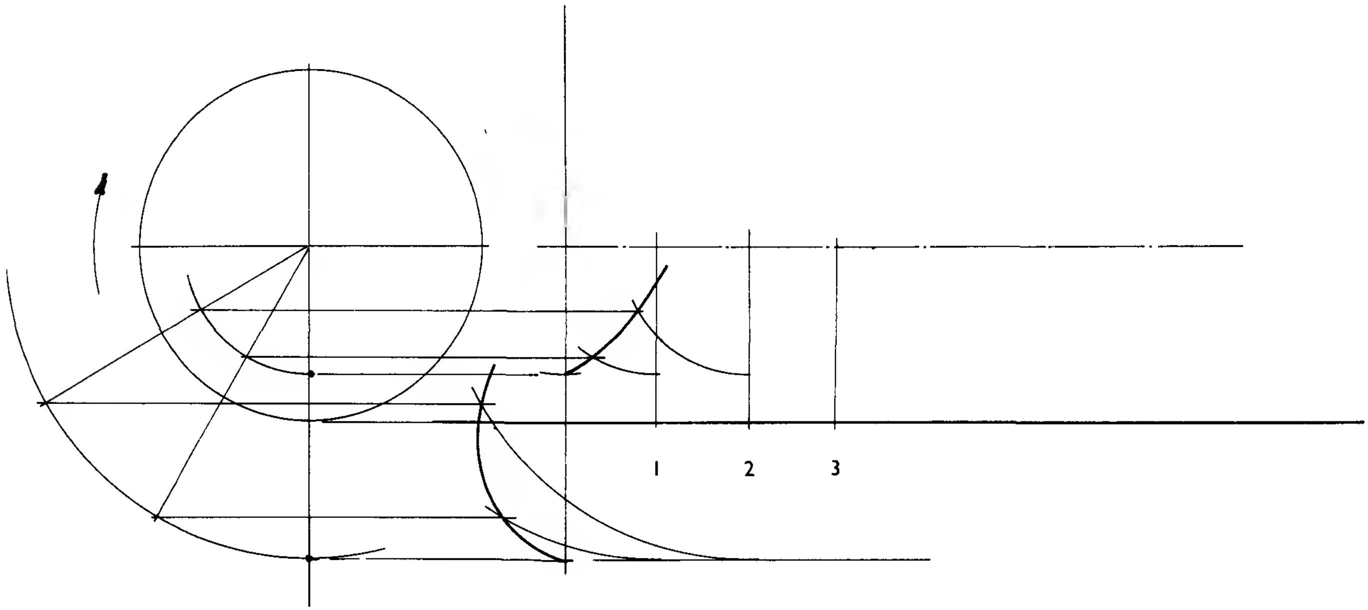


FIG 29

Curves of special interest (continued)

Involute of a circle

An involute is traced by the end of a line which rolls as a tangent, without slipping, from around the circumference of a curve. This curve is also made by the end of a cord that is kept taut as it is unwound from the circumference of a disc. The end of the cord will trace an involute. This concept demonstrates the partial construction shown in Fig. 30. In drawing, the circle is divided into twelve equal sectors using a 60°/30° set-square on a tee-square. With the same set-square, tangents are drawn from their points of intersection on the circumference of the circle. The lengths of the tangents from the circumference to the curve will be the length of the arc unwound: that is, the length of the cord *O*1 marked along the tangent from 1, and twice this amount to determine the curves intersection with the tangent from 2, measured from point 2 on the circumference, and so on. An approximate graphical method may be used—that is, chordal and not circumferencial measurement. The profile used for gear teeth is of involute form; this is comparatively easy to produce and gives the correct rolling motion as the teeth mesh together.

Exercise

Using a circle of suitable dimension, construct the involute of a circle.

Archimedean Spiral

This curve is generated by a line which rotates about its end while a point on the line is moving uniformly along it. Both angular and linear displacements are uniform. The line *OA* rotates about *O* and the point *P* moves from *O* towards *A* in equal increments with equal angular displacements (Fig. 31).

The radius is proportional to the angular displacement—$R \alpha \theta$.

Exercise

Construct an Archimedean spiral whose linear displacement shall be 90 mm in 270°.

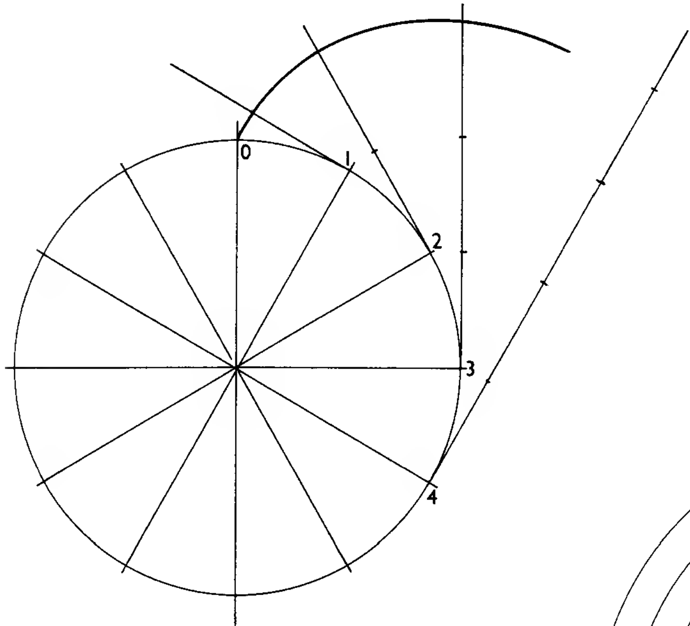


FIG 30

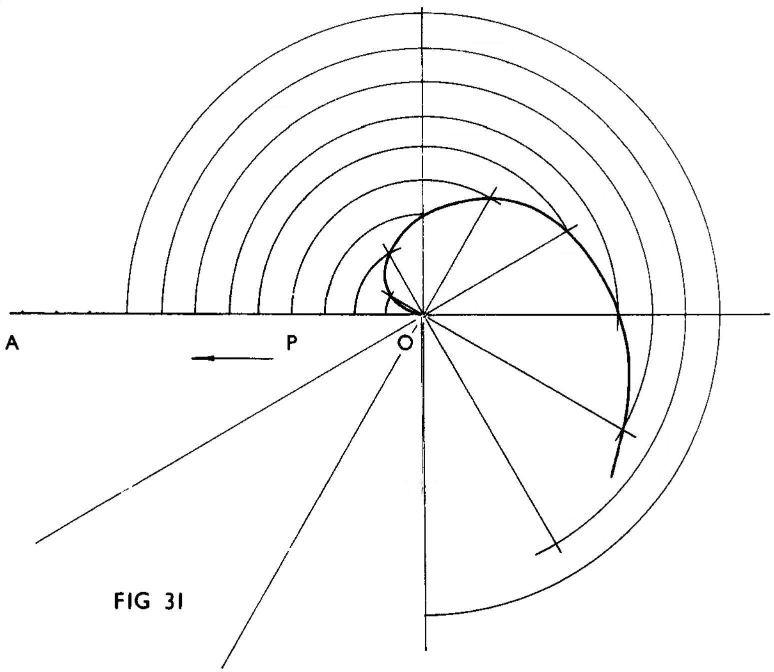


FIG 31

Curves of special interest (continued)

Helix

This curve is also of special interest, since all screw threads and coil springs are of helical form.

This curve may be defined as the locus of a point that moves on the surface of a cylinder in such a manner that the ratio of its angular movement to its linear movement is constant (Fig. 32).

The groove that is cut into the surface of a cylinder to form a screw thread advances axially the same amount for each complete turn. This axial movement per revolution is known as the pitch of the thread. In a tension spring where the wire is closely wound and each turn of wire touches its neighbour, the axial movement is equal to the diameter of the wire. With a compression spring the coils are open wound and the space between the turns of wire is normally uniform. The flutes of drills and reamers are of helical form. Here the pitch is much greater than that on screw threads and springs.

There are many cases in design where it is necessary to plot a helix. Many simple applications similar to those mentioned above may be represented in a conventional manner by replacing the helices with straight lines, and where the pitch is small in relation to the diameter the result is quite acceptable.

The helix may also be recognized as a sine wave and as the displacement curve for a point moving with simple harmonic motion.

The *helix angle* is the relationship that exists between the pitch of the helix and the circumference on which it is formed. To determine this angle a right-angled triangle is drawn, in which the opposite side represents the pitch and the adjacent side the circumference. The angle formed between the hypotenuse and the adjacent side is the helix angle (Fig. 34).

Exercise

The diameter of a cylinder on which a helix is formed is 60 mm, the axial displacement or the pitch is 120 mm. Prepare a drawing to show a complete turn.

The drawing (Fig. 33) shows a grain auger used for the bulk movement of grain, etc. It consists of a helix formed around a central spindle which rotates in a steel tube, the bottom end is exposed and the auger is driven at the top by an electric motor. Prepare a drawing to show the helical form of the auger. It will be necessary in this example to draw two helices—one on the shaft, the other on the outside which will be in contact with the inside wall of the tube. The inside diameter of the tube is 120 mm, the diameter of the central shaft 25 mm, and the pitch 120 mm.

Draw one complete turn.

Determine the helix angle of a twist drill not less than half an inch in diameter. The helix angle of a twist drill is its rake.

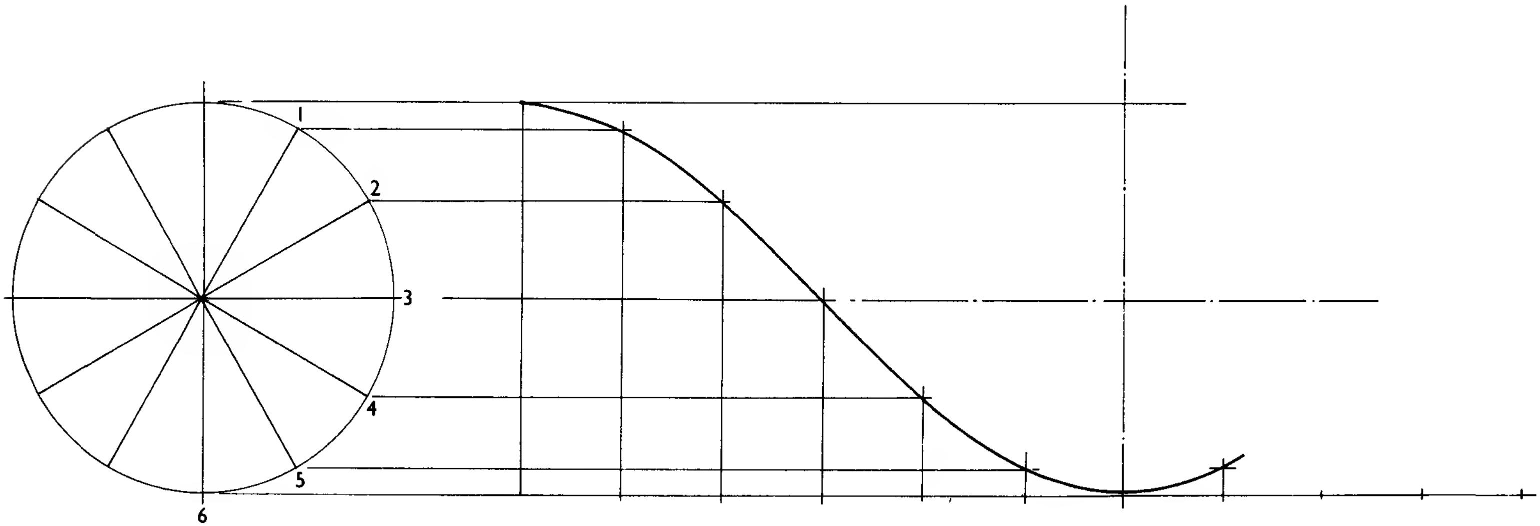


FIG 32

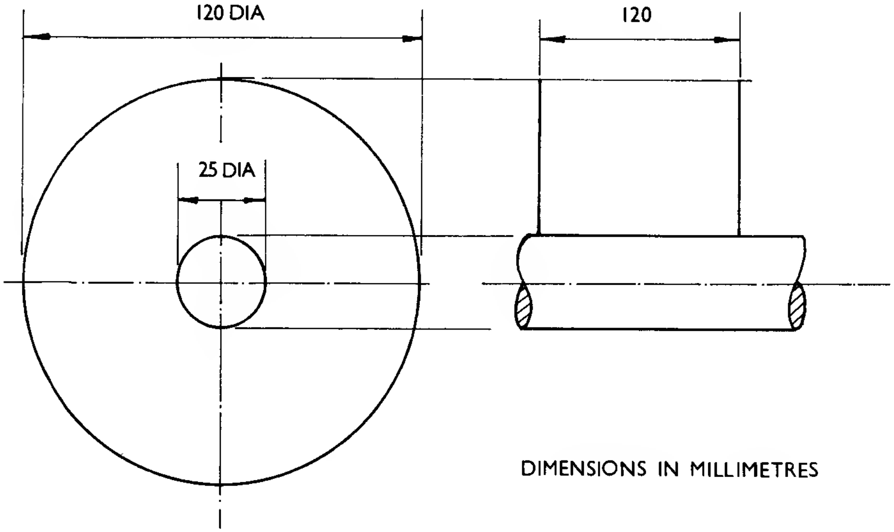


FIG 33

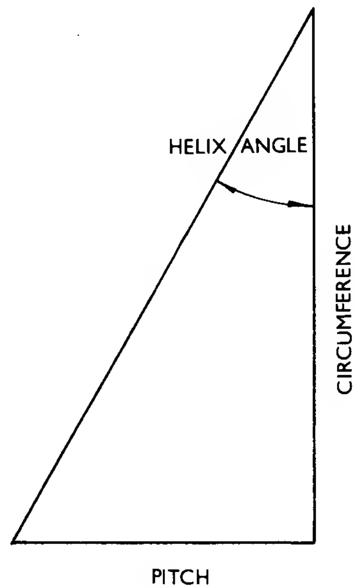


FIG 34

Curves of special interest (continued)

Link Mechanisms

It is often necessary to plot the path or locus of a point on the moving member of a machine part to ensure that it will not foul any other part of the mechanism.

The path so traced by a member may readily be determined by drawing the links of the mechanism in a number of positions, within its complete cycle of operations. These diagrams indicating movement of the mechanism and the relative positions of the links are called *configuration diagrams.*

Figs. 35, 36 and 37 show well known mechanisms which will illustrate this method.

Exercises

In Fig. 35, determine the eight positions of the crank and con-rod and establish the two extreme positions of the piston. (Reproduce Fig. 35 *twice full size* and develop your solution from this drawing.)

Determine the locus of *A* and *D:OB* rotates and the block *C* swivels. *OB* 30 mm, *OC* 45 mm, *AD* 150 mm and *AB* 50 mm (Fig. 36).

Sketch and measure the up-and-over link mechanism of a garage door, and determine, by drawing, the horizontal displacement of the lower edge of the door.

Fig. 37 shows a line drawing of the Whitworth quick return mechanism as used in a shaping machine. The large wheel rotates about O and the slotted link, O_1A, oscillates about O_1. The ram is connected to the small link AC.

Determine (*a*) the total vertical displacement of A; (*b*) the total horizontal displacement of A (i.e. the length of the stroke); (*c*) the minimum length and position of the slot in the link O_1A.

The wheel, operating the link O_1A, turns with constant angular speed: determine the ratio of the time taken for the cutting stroke F to the return stroke R.

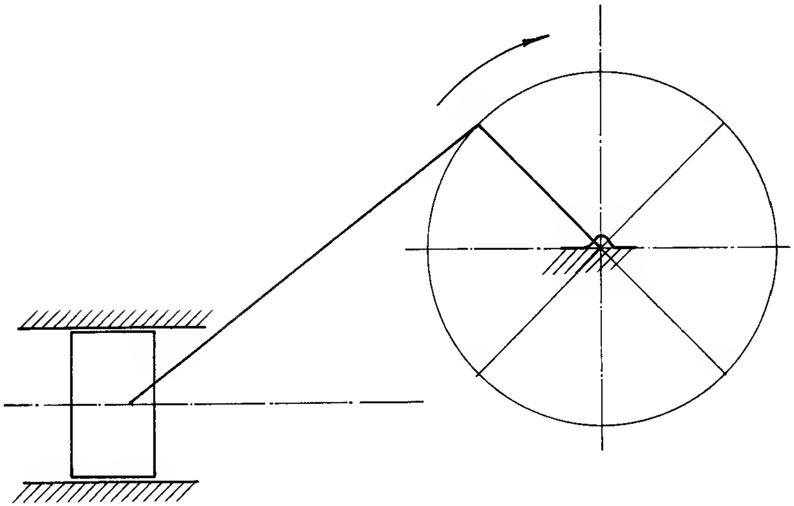


FIG 35

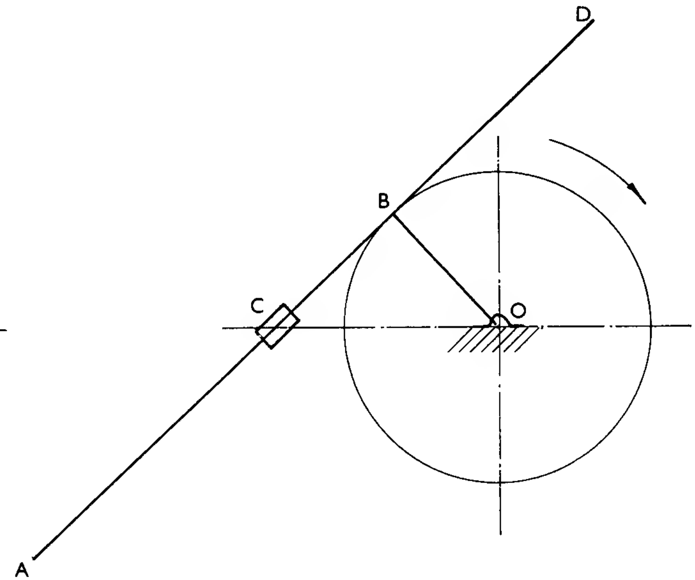


FIG 36

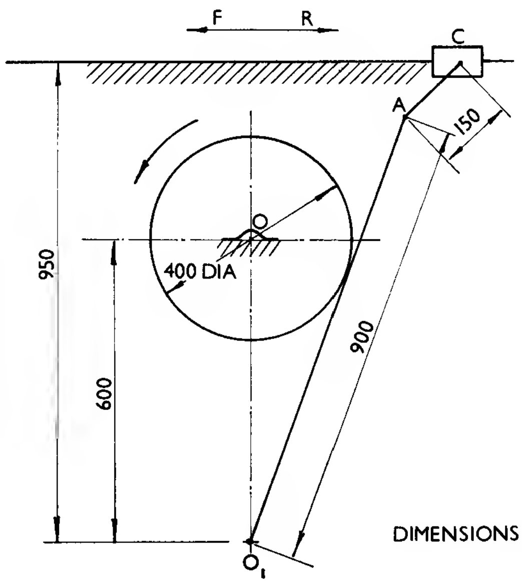


FIG 37

DIMENSIONS IN MILLIMETRES

C

Conic sections

The ellipse, parabola and hyperbola will be considered first of all as plane sections of a right circular cone; and also as curves generated by a point moving under restricted conditions.

Conics considered as sections of a right circular cone

A *right circular cone* is formed when a right-angled triangle is spun about one of the sides containing the right-angle. The cone is said to be *generated*, and the *generators* are the lines forming the cone. The cone is said to be *right* as the axis is at right-angles to the base which is *circular*.

When the section plane cuts all the generators and is parallel to the base of the cone, a circle will be revealed (Fig. 38a). If the section plane is inclined to the horizontal, but not at an angle greater than the inclination of the generator, the cut surface will reveal an ellipse (Fig. 38b); a section plane parallel to a generator will expose a *parabola* (Fig. 38c). Fig. 38d shows a *hyperbola*, that is, the section produced by a cutting plane which is inclined to the horizontal at an angle greater than the inclination of the generator and which will penetrate both parts of the double cone on the same side of the axis.

The ellipse is a closed curve; a parabola is an open unending curve with only one branch and the hyperbola, which is slightly flatter, has two unending branches extending in opposite directions.

From the above paragraphs it will be appreciated that there is, in a specific cone, a family of circles, ellipses, parabolas and hyperbolas. There is also a special family of hyperbolas called *rectangular hyperbolas* and they will be revealed when the cutting plane is at right-angles to the base of a cone the apex of which is a right-angle. A rectangular hyperbola will *not* be revealed when the cutting plane, although at right-angles with the base, passes through the apex of the cone.

Name the conic sections revealed by the cutting planes numbered one to ten on the elevation of the cone shown in Fig. 39.

What plane figure will be revealed when the cutting plane passes through the apex of the cone?

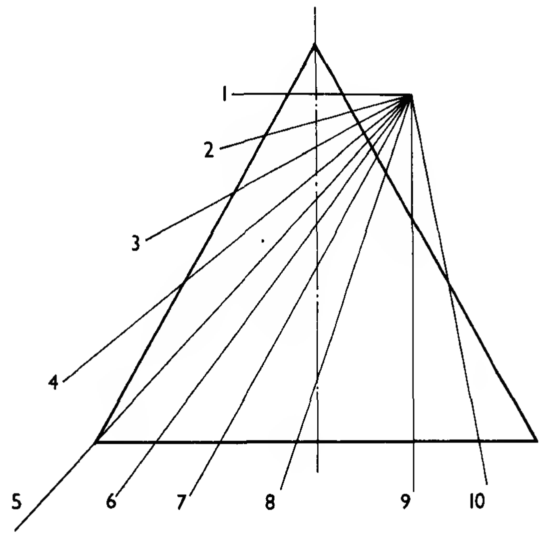


FIG 39

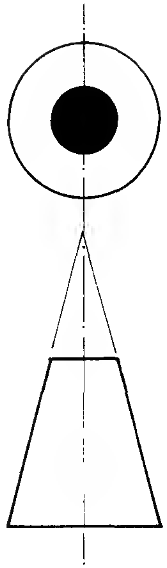
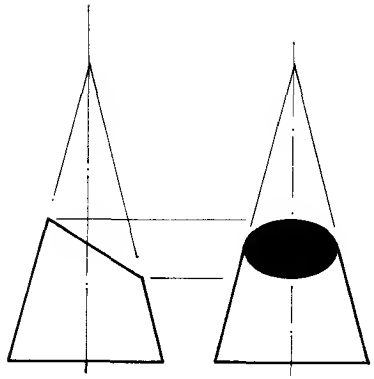
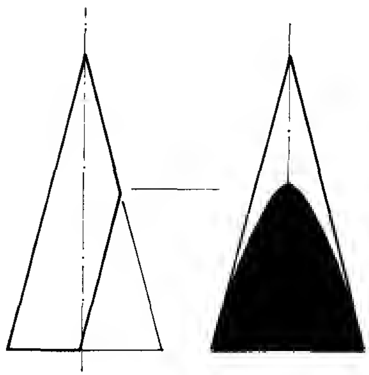


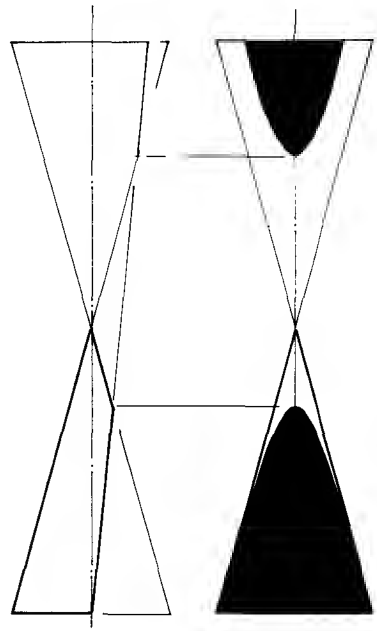
FIG 38 a CIRCLE



b ELLIPSE



c PARABOLA



d HYPERBOLA

Conic sections (continued)

Some basic constructions are now considered of the ellipse, parabola and hyperbola.

Ellipse

This curve is closed. The maximum and minimum dimensions of the ellipse are called the *major and minor axes*; they may vary considerably. Like all conic sections, the ellipse has a focus: the parabola has one, the hyperbola has one for each branch and the ellipse has two.

Take a piece of cord. Tie two knots in it, about 150 mm apart. Pin the knots to the board so that they are less than 150 mm apart. Tighten the cord by putting a pencil behind it and, keeping the cord taut, trace out an ellipse (Fig. 40).

The sum of the distances from the pins *F* to any point on the curve *P* is the length of the cord between the two knots. The pins mark the focal points of this ellipse. Unpin the cord and stretch it from knot to knot along the main axis of the ellipse.

This is the simplest method of producing an ellipse and demonstrates that *the sum of the distances from the focal points to a point on the curve is always constant and equal to the major axis.*

Another method used to construct an ellipse, given the major axis and the foci, is to strike out a series of arcs from each of the foci which together will equal the length of the major axis (Figs. 41 and 42).

Using this method draw an ellipse, the foci of which are 90 mm apart and the major axis is 140 mm long. Measure the minor axis.

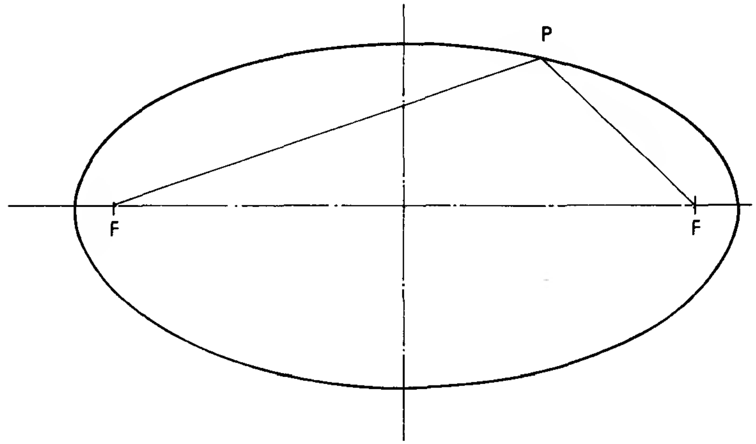


FIG 40

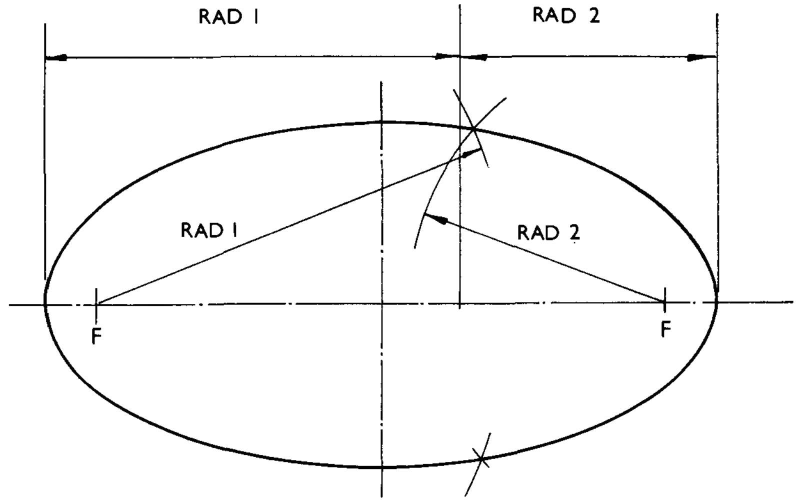


FIG 41

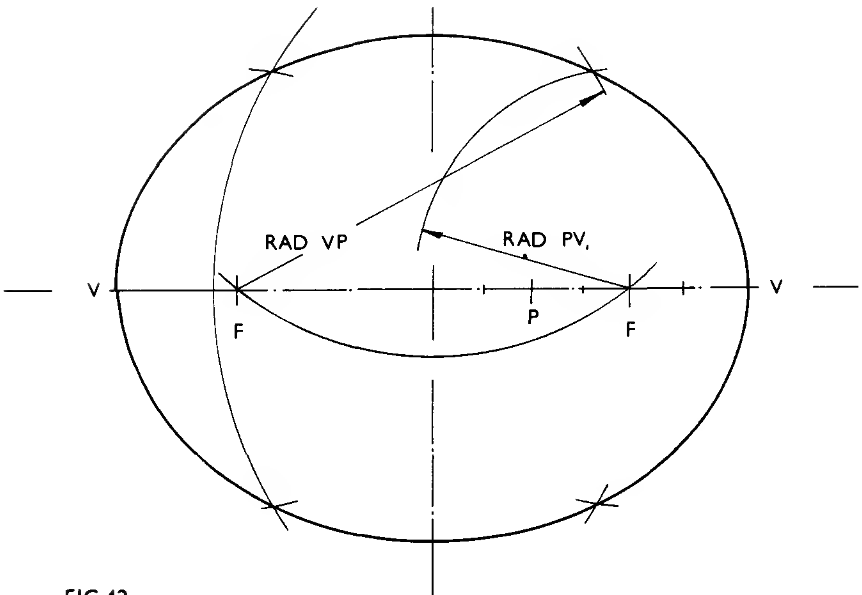


FIG 42

Conic sections (continued)

The following methods of construction for the ellipse are the most popular, when given the dimensions of the major and minor axes. All methods are partially demonstrated on the adjacent page; using suitable dimensions, try several or all of these constructions.

1. The trammel method (Fig. 43)

This is the most convenient way of constructing an ellipse, if the axes are known. A piece of card is marked as shown. As points 1 and 2 are moved along the major and minor axes, point *P* traces out the curve. Mark positions on the curve at regular intervals.

2. The rectangular method (Fig. 44)

In this construction a rectangle is drawn, the centre lines of which are equal to the major and the minor axes. Each half of the major axis is divided into a number of equal parts and the side of the rectangle equal in length to the minor axis is divided into the *same number* of equal parts. Radial lines are drawn from the extremities of the minor axis through these points. The points of intersection of these radial lines will be on the required curve. This procedure may be repeated in the other quadrants or the points obtained may be transferred by projection: a much quicker method.

3. The method of auxiliary circles (Fig. 45)

Draw two concentric circles centre *C* whose diameters are equal to the major and minor axes. From the centre of these circles draw several radial lines, cutting the large circle at *A* and the small circle at *B*. At *A* draw a vertical. At *B* draw a horizontal. These intersect at *P*. *P* is a point on the ellipse. Repeat this process, using other radial lines drawn through the centre *C*. This procedure may be repeated in the remaining quadrants or the points already obtained may be transferred by projection.

4. Approximate method of arcs (Fig. 46)

Draw a rectangle, the centre lines of which are the axes of tne required ellipse. Join a corner of the rectangle so formed with the extremity of the minor axis *A*. Bisect the side of the rectangle representing half the minor axis *B*. Join *BE* and *CD*. Bisect *CD* and *DE*. The intersections of these bisectors with the major and the minor axes produced will give the centres of suitable arcs—four of which will compose *an approximate ellipse*.

Mark the positions of the foci on the ellipses you have drawn.

Exercise

Design an elliptical instrument panel for a small car. It must contain three circular instruments, one of 80 mm diameter and the other two of 45 mm diameter. (From coloured paper or card cut discs to represent the instruments and arrange them in a pleasing way before deciding upon the final complete design.)

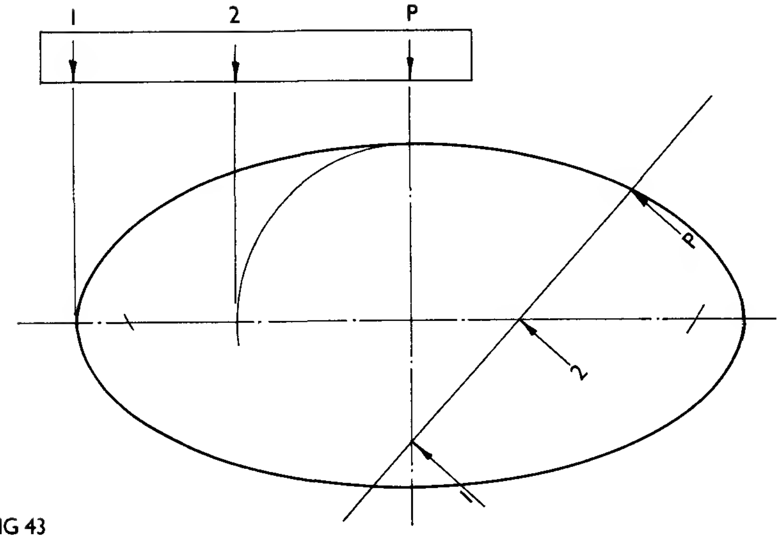


FIG 43

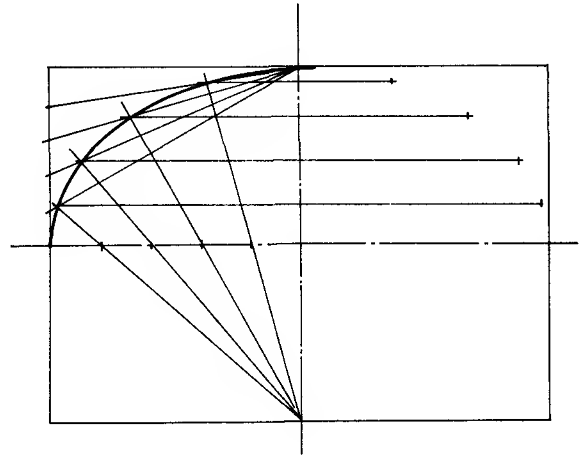


FIG 44

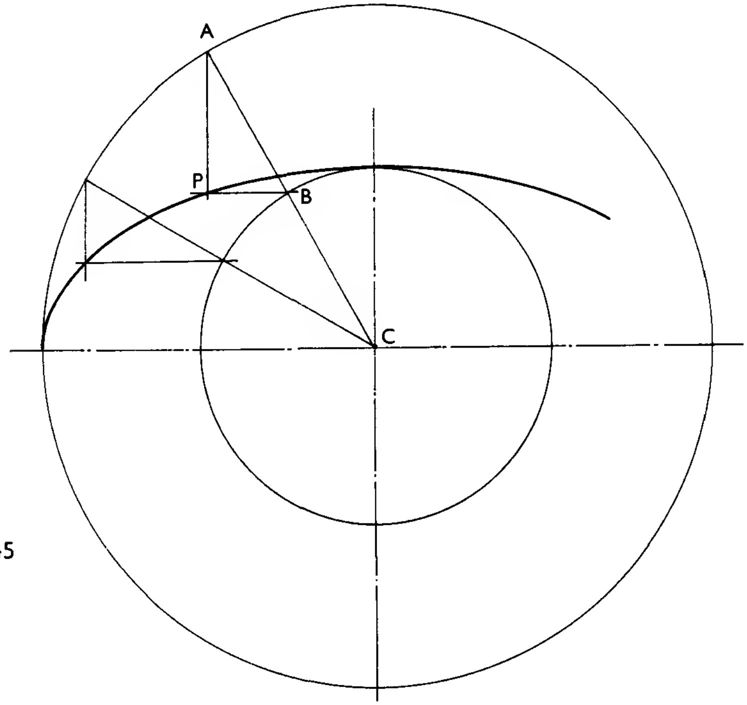


FIG 45

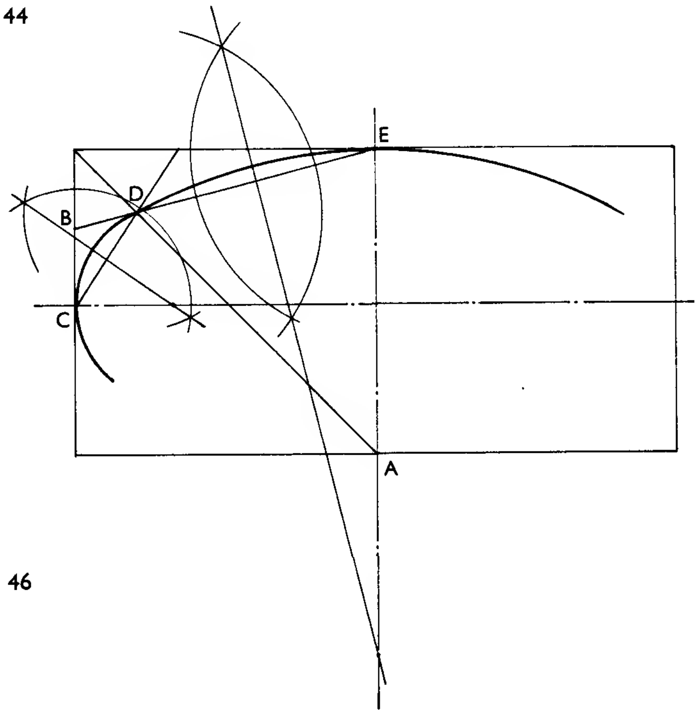


FIG 46

Conic sections (continued)

Parabola

The dimensions of a parabola are often given as base width and vertical height. In bridge design these dimensions are referred to as the *span* and the *rise* and will be the dimensions of the rectangle that will contain the parabola.

When a parabola is spun about its axis of symmetry, as an isosceles triangle may be spun to generate a cone, the parabola forms or generates a paraboloid. The section of a headlight reflector is parabolic and the bulb is at the focus. Another splendid example of a paraboloid is the reflecting bowl of the radio telescope at Jodrell Bank.

The following constructions may be used when the dimensions of the enclosing rectangle are known, that is, base width and vertical height.

1. Rectangular construction (Fig. 47)

This is a very easy construction. The axis of the parabola is drawn and a series of equidistant vertical lines are drawn parallel to it. An equal number of divisions is also marked on the side of the rectangle in which the parabola is to be drawn and a series of radial lines are drawn to these points from the *vertex*. The intersection of these radial lines with the corresponding vertical lines will determine points on the parabola The other half of the parabola may be determined by the same method or by projection.

2. Rectangular construction using measured abscissae (Fig. 48)

Again a straight-forward method. A property of the parabola is that the *abscissa*, that part of a diameter of a conic between its vertex and an *ordinate*, is proportional to the product of the parts into which it divides the double ordinate.

3. Fig. 49 shows the same drawing turned through 90°.

The distances measured along the abscissae, which form a *datum line* containing the vertex and at right-angles to the axis, are proportional to the square of their distances from the axis. The result is the same as that in 2 above. Another way of writing this is the expression $y = x^2$.

Exercise

By one of the above methods, inscribe in a rectangle 80 mm × 140 mm, a parabola, the axis of which is parallel with the longest side of the rectangle. Then repeat the drawing, using a different method.

Hyperbola

The *rectangular hyperbola* is a curve which describes mathematically the behaviour of a gas when compressed or allowed to expand, and was established by Robert Boyle in 1662. The curve indicates the relationship that exists between pressure and volume, in a gas at constant temperature: the volume varies inversely as the pressure. The product of the pressure and the volume is a constant $PV = C$.

4. The rectangular hyperbola (Fig. 50)

The two lines bounding the hyperbola are called asymptotes and the curve of the hyperbola is *asymptotic* to the lines: though they will always draw nearer together they will never meet. As it is a rectangular hyperbola that is being considered, draw the asymptotes at right-angles to each other. Then select a point P and through it draw a vertical and a horizontal line. For the purpose of this example P is arbitrary, but could be regarded as the volume and pressure of a gas before it was subjected to compression or expansion.

Fig. 50 shows how additional points on the curve may be determined.

An example to conclude this section appears on page 44.

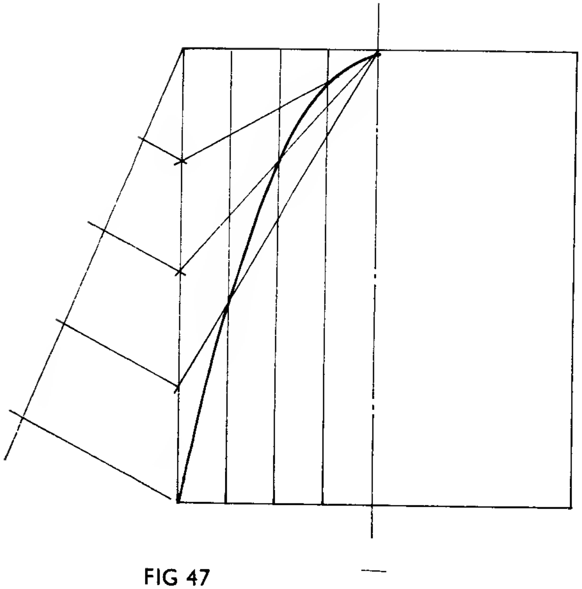


FIG 47

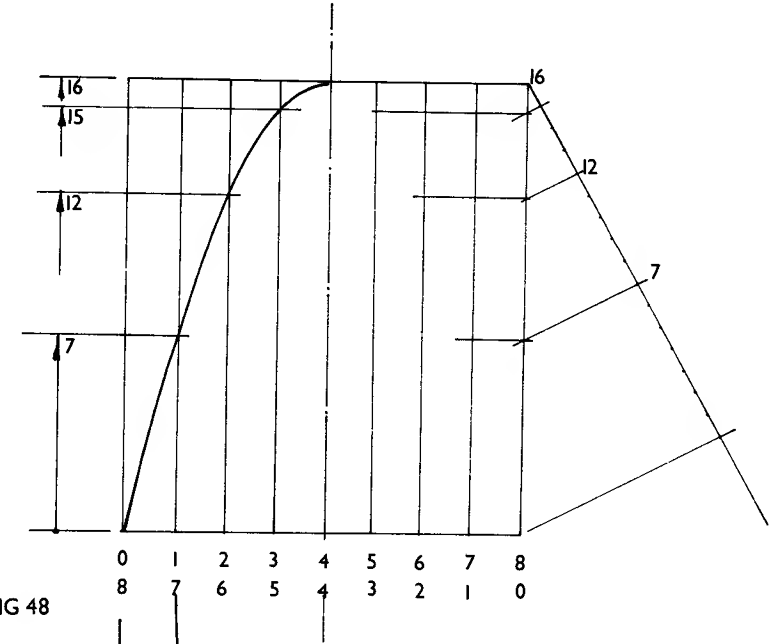


FIG 48

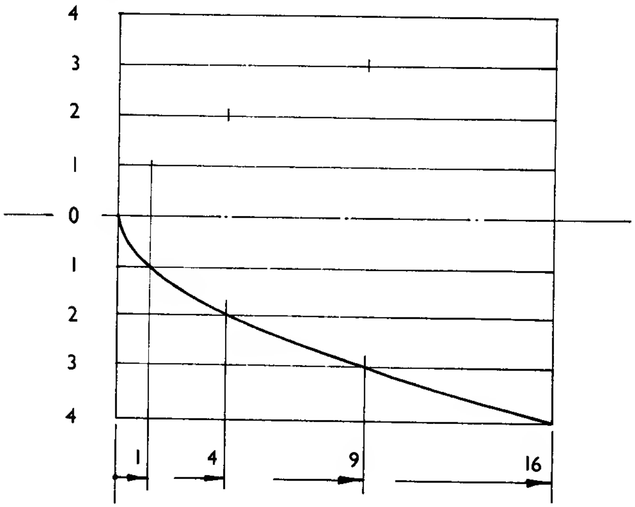


FIG 49

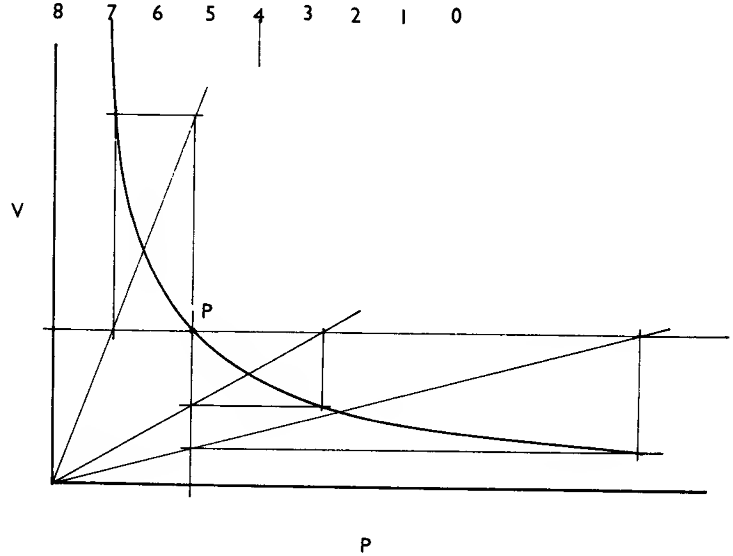


FIG 50

Conics considered as plane loci

The following paragraph introduces the terminology commonly encountered when dealing with conic sections.

Look at Figs. 51, 52 and 53. The inscribed sphere in the cone is called the *focal sphere* and the point where this sphere touches the section plane will determine the *focus of the conic* (*F*). The cone and the sphere touch and form a circle in a plane which is horizontal. The intersection of the horizontal plane and the section plane determines the position of the *directrix* (*D*). The *axis* of the conic passes through the focus and the *vertex* (*V*), the point at which the curve intersects the axis. A straight line connecting two points on a conic is called a *chord* and if this should pass through the focus it is referred to as a *focal chord*. A *diameter* of a conic is the line through the mid-points of parallel chords. A perpendicular drawn from the axis containing the foci to the curve is called an *ordinate* and, if produced to cut the curve on the other side of the axis, a *double ordinate* is formed. For any point on a conic, the ratio of the distance from the focus to the perpendicular distance from the directrix is a constant and is called the *eccentricity* of the conic.

A conic may also be defined as the locus of a point which moves in a plane so that the ratio of its distance from the focus to its perpendicular distance from the directrix is constant. This ratio, termed the eccentricity, will dictate the type of curve traced. For the parabola this value will be equal to unity, greater for the hyperbola and less for the ellipse.

It is interesting to note the derivation of the words ellipse, parabola and hyperbola. These curves, as sections of a cone, were studied by the ancient Greeks:

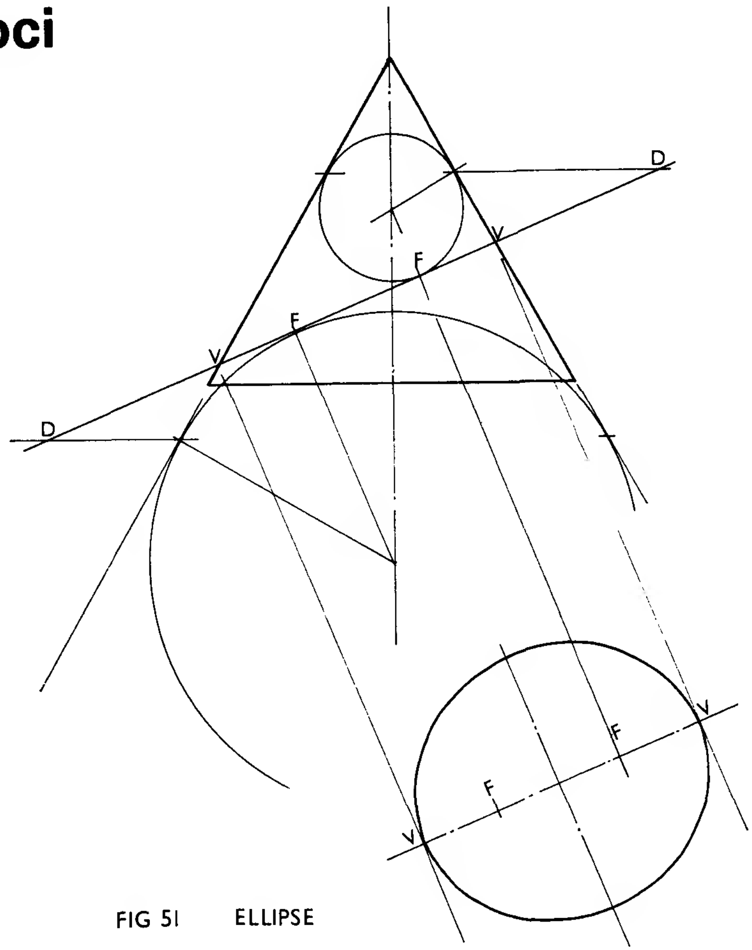


FIG 51 ELLIPSE

Ellipse—Greek *ellipsis*—falling short—eccentricity less than 1 (one)

Parabola—Greek *parabole*—placing side by side—eccentricity equal to 1 (one)

Hyperbola—Greek *huperbole*—an excess—eccentricity greater than 1 (one).

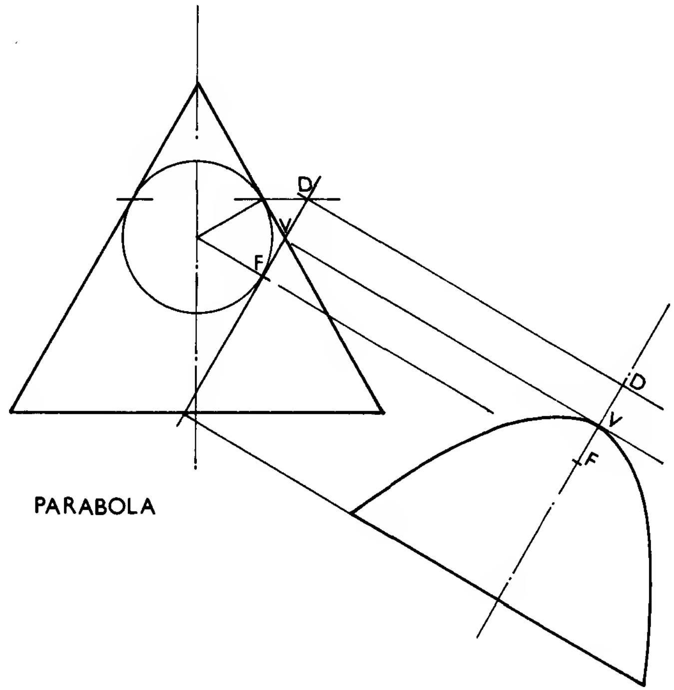


FIG 52 PARABOLA

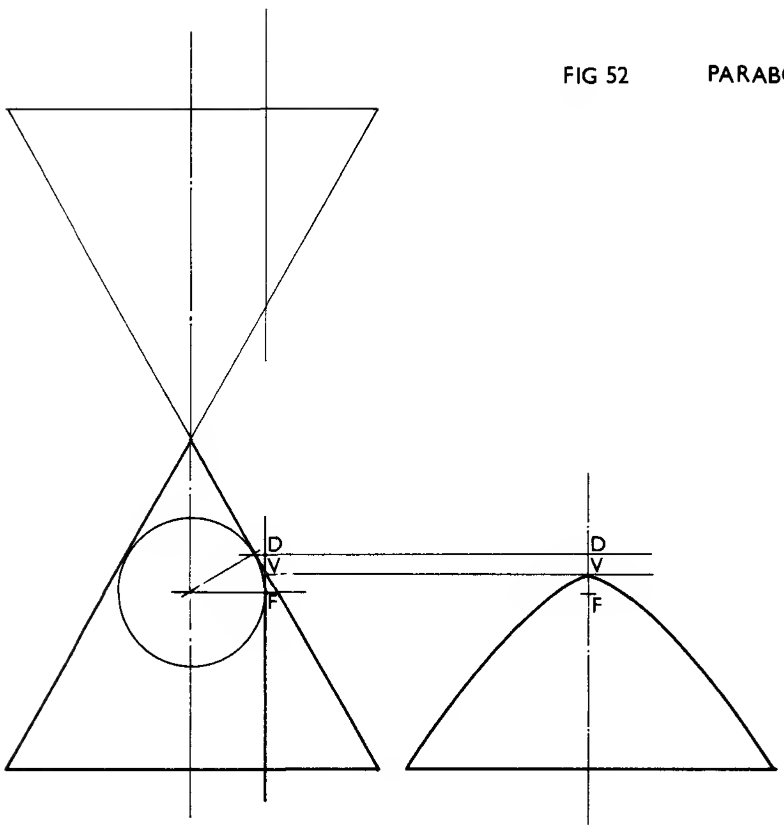


FIG 53

HYPERBOLA

Conics considered as plane loci (continued)

As has been established on preceding pages a specific relationship exists between the distance from a point on the curve to the focus and the perpendicular distance of the point from the directrix. This relationship is constant and is called the eccentricity. Eccentricity is normally expressed fractionally.

Given the eccentricity and the focus, it is a comparatively straight-forward matter to construct a suitable simple proportional scale and develop the curve.

1. The easiest of the three curves to draw is the parabola. Its eccentricity is *one*. This means that the distance from the curve to the directrix will always be equal to the distance from the same point on the curve to the focus. Consider the axis and the vertex. The vertex will lie mid-way between the directrix and the focus (Fig. 54). The construction is straight-forward (Fig. 55): a series of suitably placed parallel ordinates are drawn, and a series of arcs, with radii equal to the distance from the directrix, are struck from the focus to intersect the corresponding ordinates.

2. For the ellipse, the fraction to denote the eccentricity, will fall short of one—say $\frac{3}{4}$. The distance from the focus to the curve will be three units and from the same point on the curve the perpendicular distance to the directrix will be four units (Fig. 56). A suitable scale is shown in Fig. 57: the base of the triangle is four units and the opposite side is three units. A series of ordinates will divide this triangle into a family of similar triangles in which the ratio of the base to the height is four to three; the distance from the directrix, is the base of the triangle, and the distance from the focus is the height of the triangle. The completion of the curve is now a simple matter.

3. The hyperbola is constructed in a similar manner.

Exercise

With a focus 60 mm from the directrix construct a parabola,
an ellipse, eccentricity $\frac{3}{5}$,
a hyperbola, eccentricity $\frac{4}{3}$.

This exercise is to be considered with the topics on page 40.

Exercise

On graph paper draw a rectangular hyperbola. The point P is to be on the intersection of two lines.

Using similar graph paper, cut out a rectangle identical with the one on your drawing whose corner is at P. Calculate its area, and cut out several other rectangles, two of each, of the same area but different shape.

On detail paper draw two axes at right-angles and fit the original rectangle into the corner so that its position corresponds to the original drawing. Arrange the pairs of rectangles so that their long edges lie from the corner along the axes.

On the detail paper mark the position of the outer corner of each rectangle. Remove the rectangles and draw in the curve.

Superimpose the detail paper on the axes of your original drawing.

On the detail paper, draw three different rectangles; two sides of each must coincide with the axes and the outer corner must lie on the curve.

What relationship exists (*i*) between the areas of these rectangles, and (*ii*) between their areas and the areas of the rectangles used in drawing the curve?

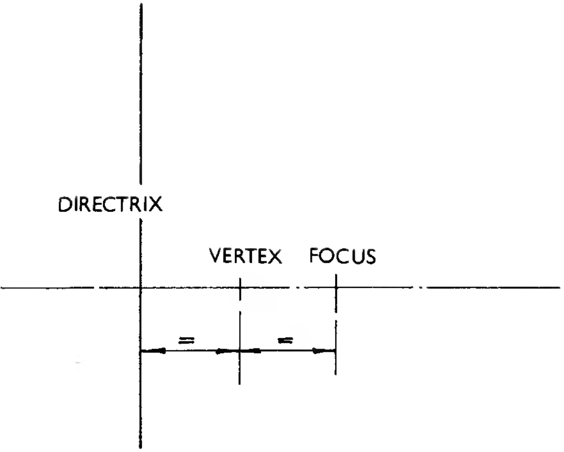


FIG 54

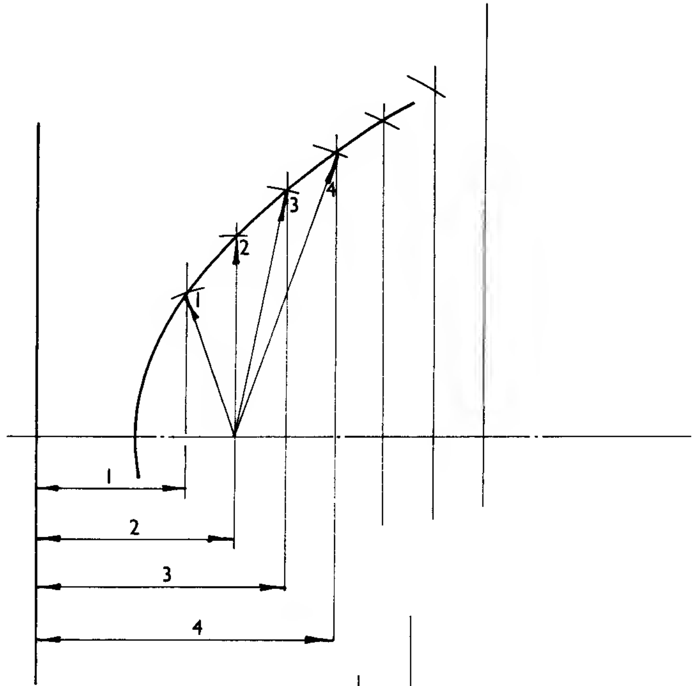


FIG 55

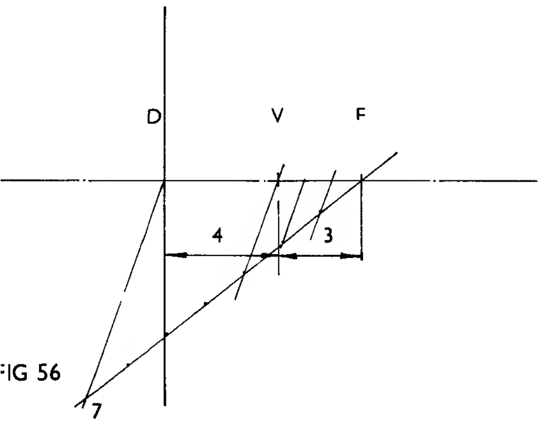


FIG 56

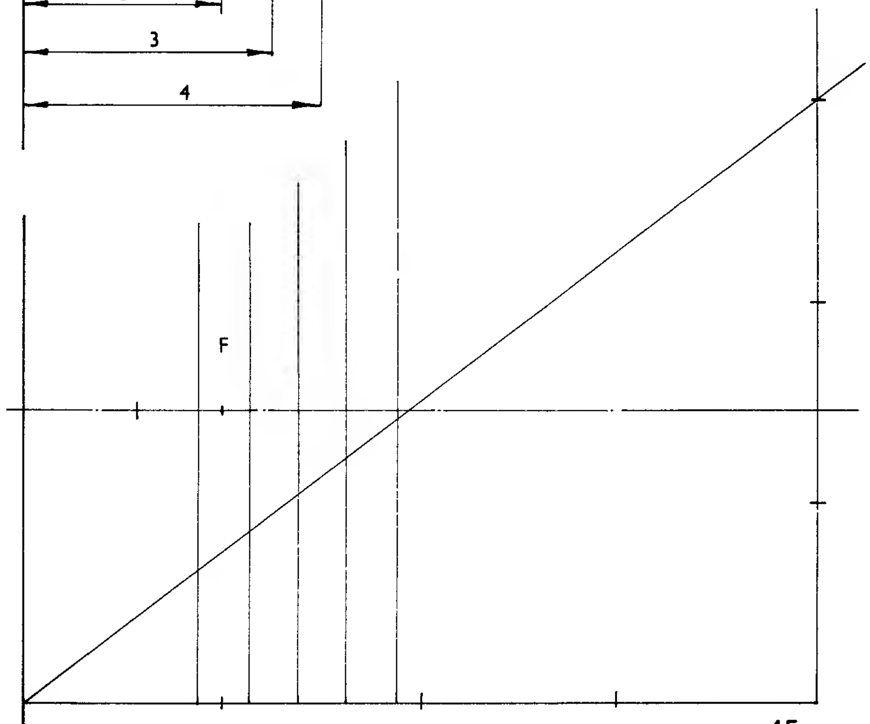


FIG 57

SECTION TWO

The methods of orthographic projection

All orthographic projections are representations in two dimensions of three-dimensional objects.

Every drawing is a representation of shape, and when fully presented, labelled and dimensioned it must convey a complete specification. Not only must a drawing describe all the necessary manufacturing details, it must also show every detail of shape in such a way that no misunderstanding can arise.

A spoken or written statement should be clear, precise and without ambiguity if it is to convey a clear picture. A technical drawing must possess the same qualities, as it too is a method of communication.

The above statement makes clear that careful thought must be given to the *choice* and *number* of views. It is often necessary to present three views to describe an object adequately.

Orthographic projection

In effect space is divided into four quadrants by two *planes*, one vertical and the other horizontal. The object to be drawn is placed in the *first* or *third quadrant* (Fig. 58), and lines, called *projectors*, are drawn, from salient points on the object, perpendicular to these planes. The view so obtained on the *vertical* plane is called the *elevation* and the view on the horizontal plane is called the *plan*.

Additional views may be projected onto an auxiliary plane, perpendicular to the other two, and these projections are called *end views* or end *elevations*.

In technical drawing these projections are drawn on a single flat surface, the planes being considered as opened out about the lines of intersection of the horizontal and vertical planes. This *datum line* is referred to as the *xy* line, a line which divides the horizontal and vertical planes.

The presentation of views so obtained when an object is considered in the first angle or quadrant, constitutes the basis of *British Standard First Angle Projection*.

The *plan will always appear* under the elevation, and the *end view* will always appear adjacent to the elevation and on the *opposite side from which it is viewed*. Viewed from the *left* the projection will appear on the *right of the elevation* and vice versa.

The third angle projection, once referred to as the American system, is now almost universally accepted and is widely practiced in this country. Here the object is placed in the third angle or quadrant, the planes being assumed transparent and placed between the object and the observer. When the planes are opened out the *plan* will appear *above the elevation* and the *end views* on either side of it.

A general note concerning all projection

The *elevations* are always in *horizontal alignment* and the *plan* is always in *vertical alignment* with the elevation.

The *horizontal plane* (HP) always presents the *plan* and the *vertical plane* (VP) always presents the *elevation* and *end views*, often referred to as elevations.

The best method to use

For small and medium sized orthographic views, neither method has any real advantage. For large views, however, third angle projection has an advantage in that the end views and the plan of the object appear adjacent to the elevation they describe, and this enables a large drawing to be read more easily.

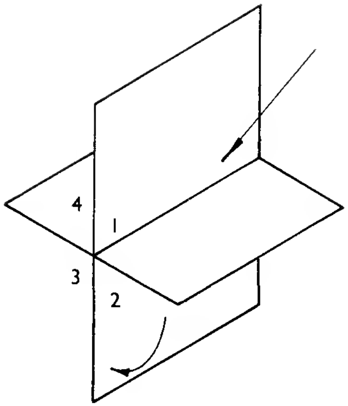
Figs. 58 and 60 show the technique of first and third angle projection—a pictorial presentation on the left-hand page and the orthographic drawing on the right-hand page, Figs. 59 and 61.

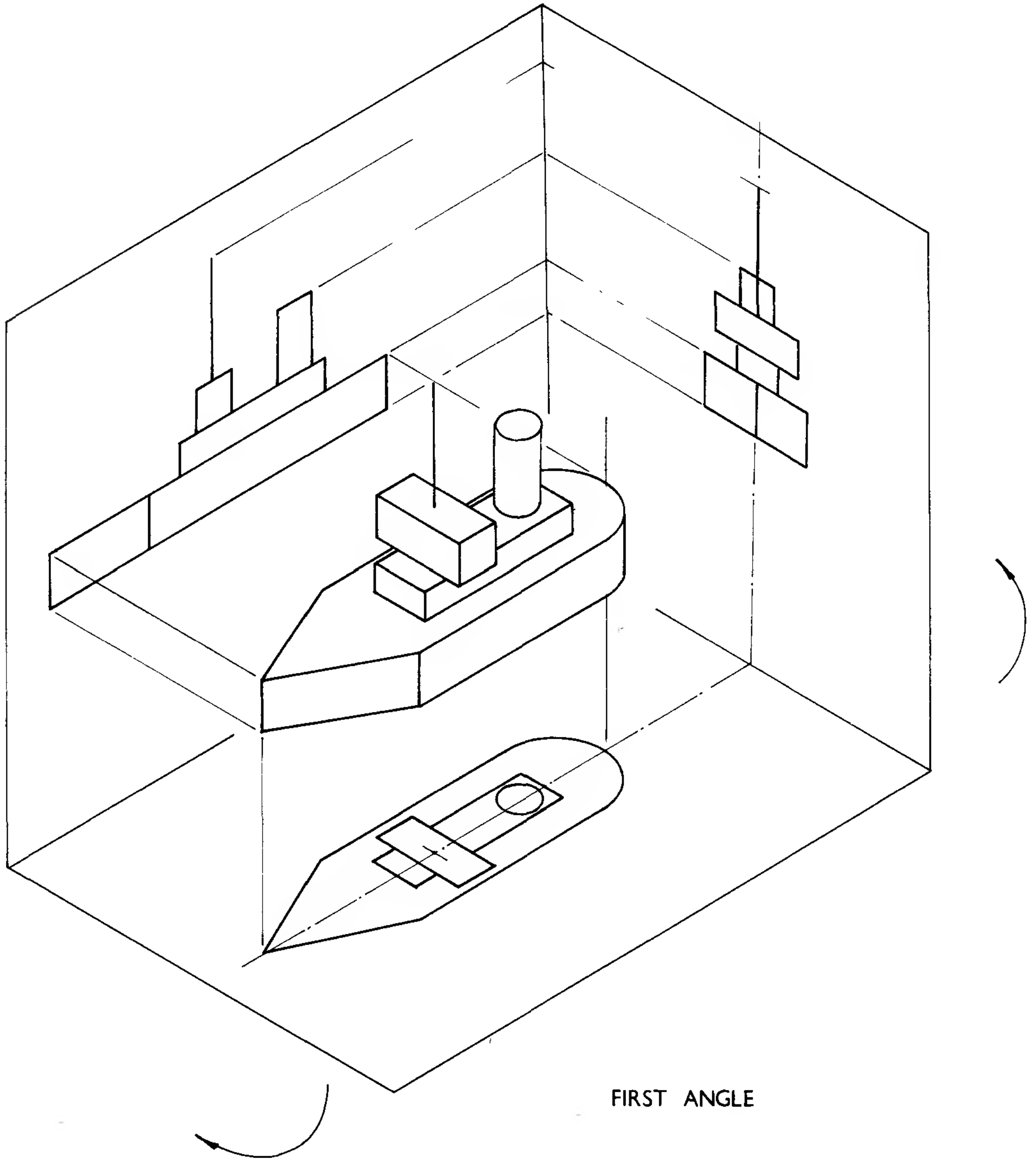
Exercise

Transfer the orthographic drawings of plan and elevation shown on the right-hand pages, Figs. 59 and 61, to a sheet of drawing paper. Take off the dimensions with dividers or a rule and draw the end elevations.

The subsequent pages (Figs. 62 and 63) present an *isometric* drawing in the centre of the page. Take dimensions from it, and draw the plans and elevations shown in the corners of the page.

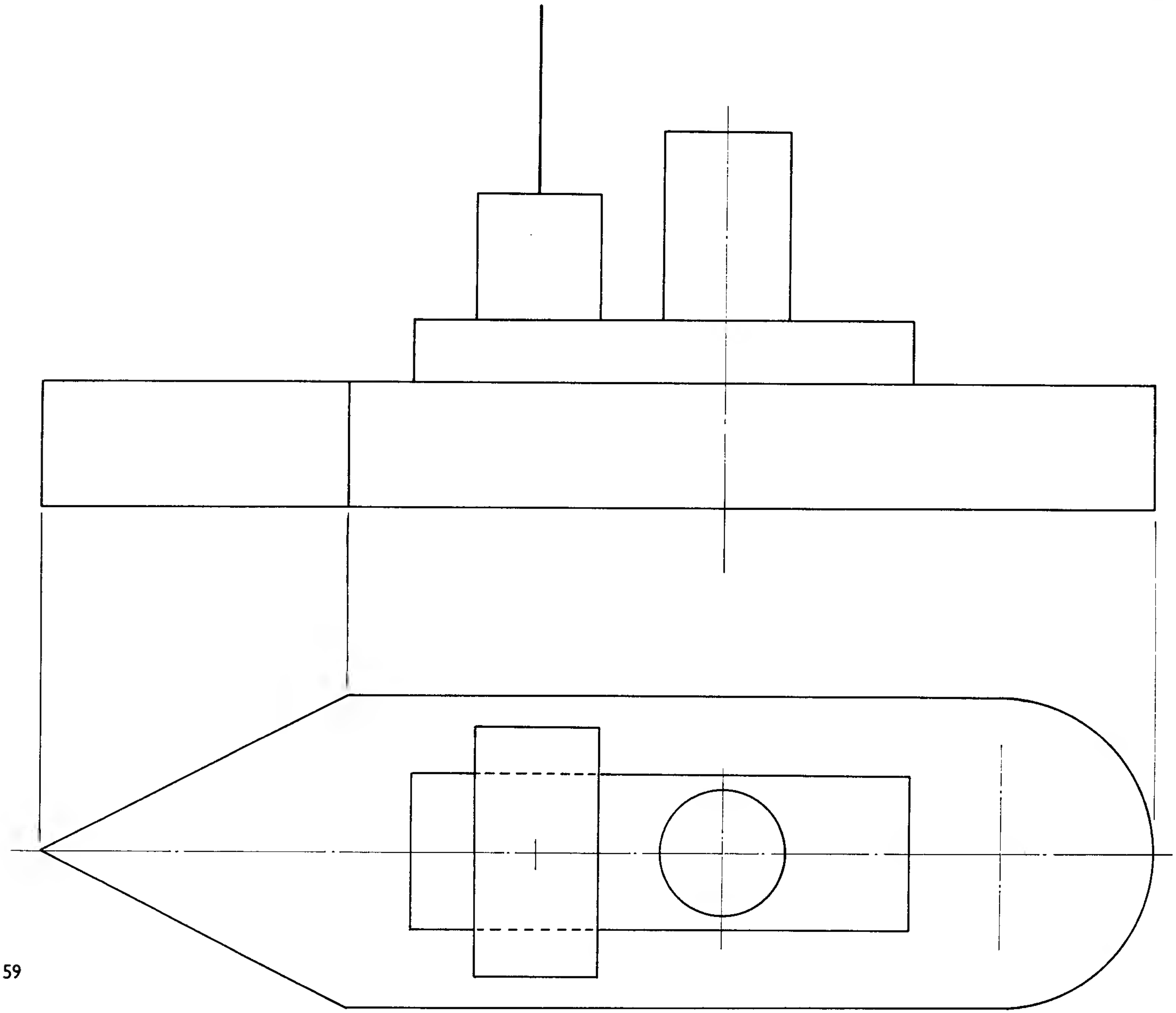
It will also be evident from the smaller drawing showing the two planes and four quadrants (Fig. 60), why the second and fourth quadrants are not considered. When unfolded, the vertical plane remaining vertical and the horizontal plane, in the first quadrant, being lowered, the projections on the vertical and horizontal planes in these quadrants will be superimposed.





FIRST ANGLE

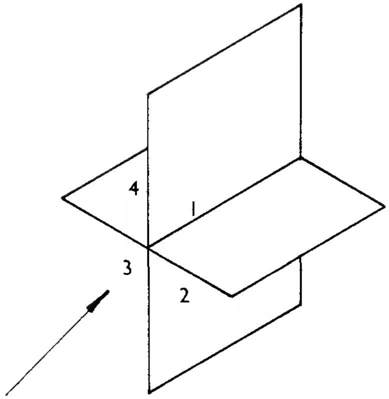
FIG 58



G 59

D

FIRST ANGLE DIMENSIONS IN MILLIMETRES



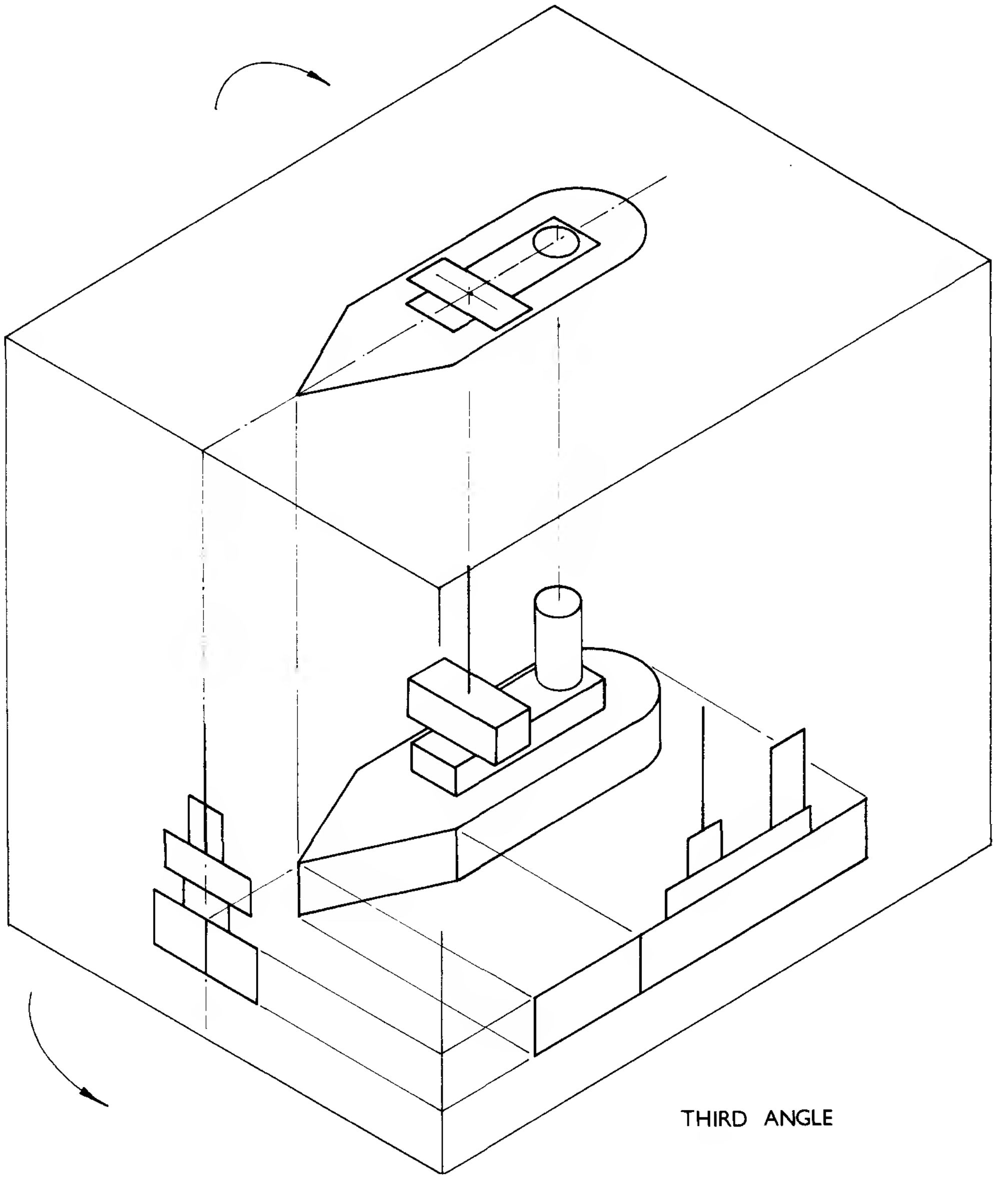


FIG 60

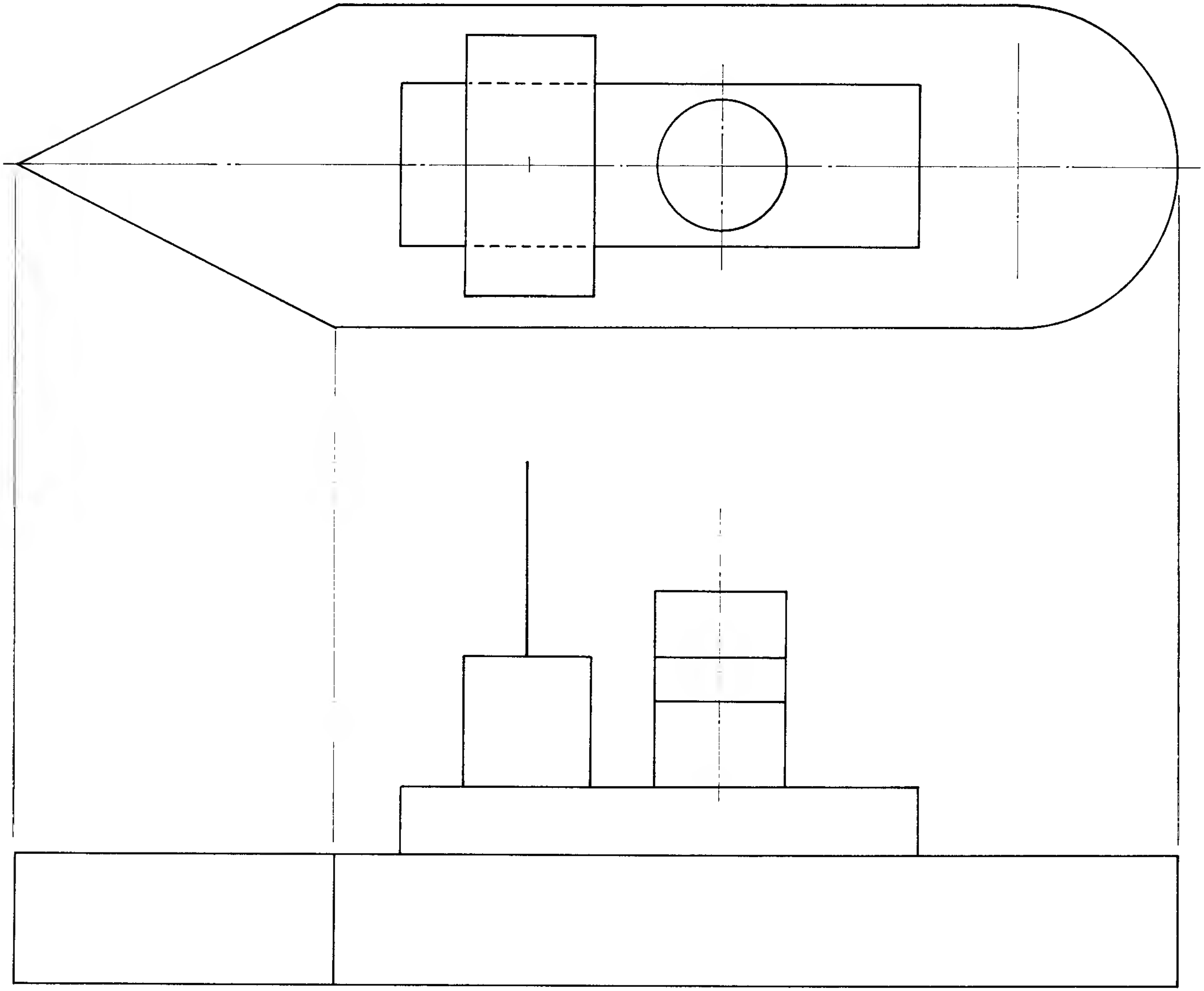


FIG 61

THIRD ANGLE DIMENSIONS IN MILLIMETRES

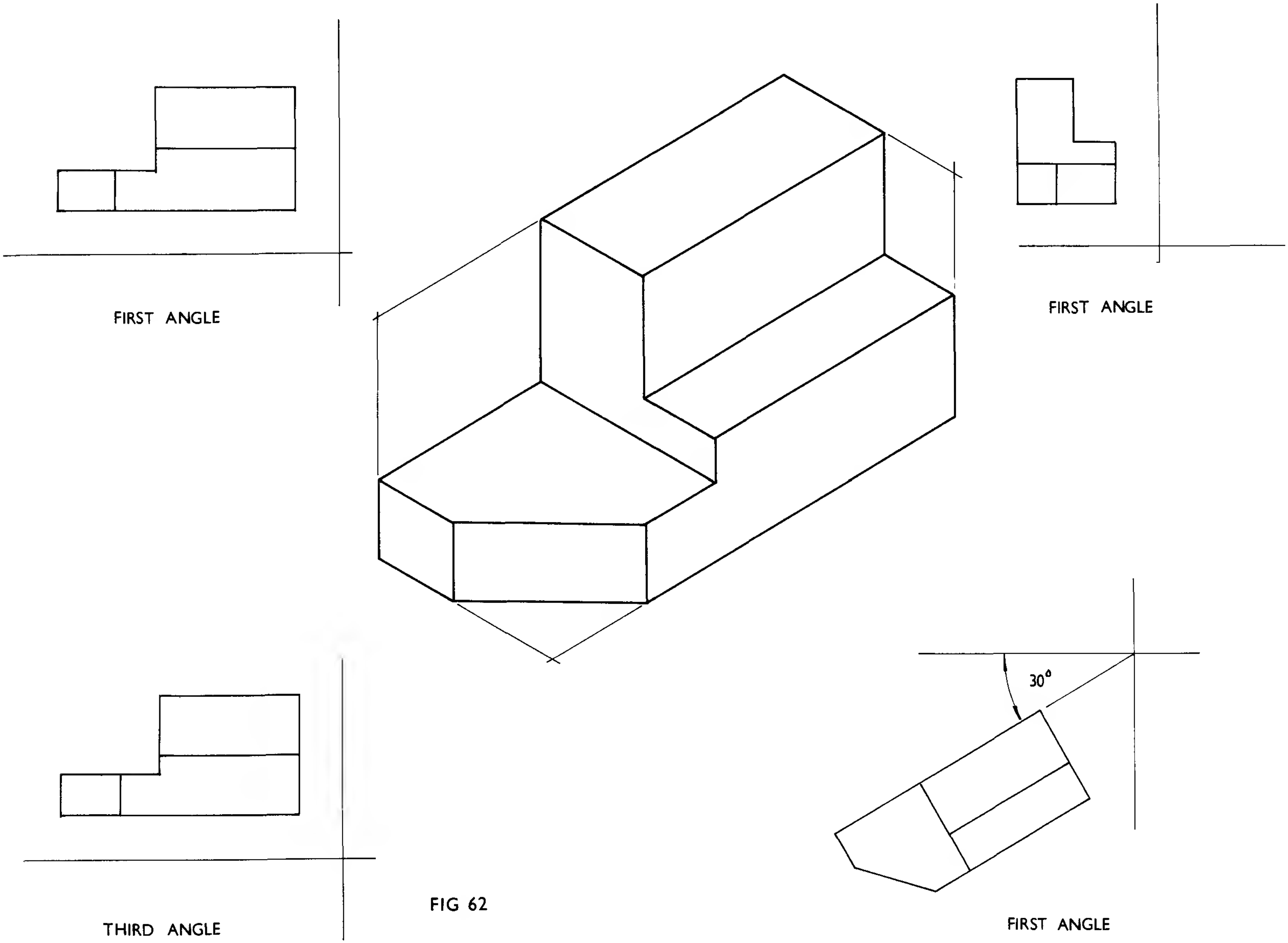
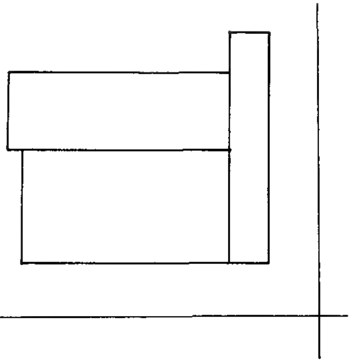
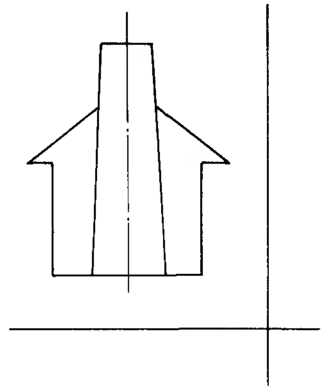


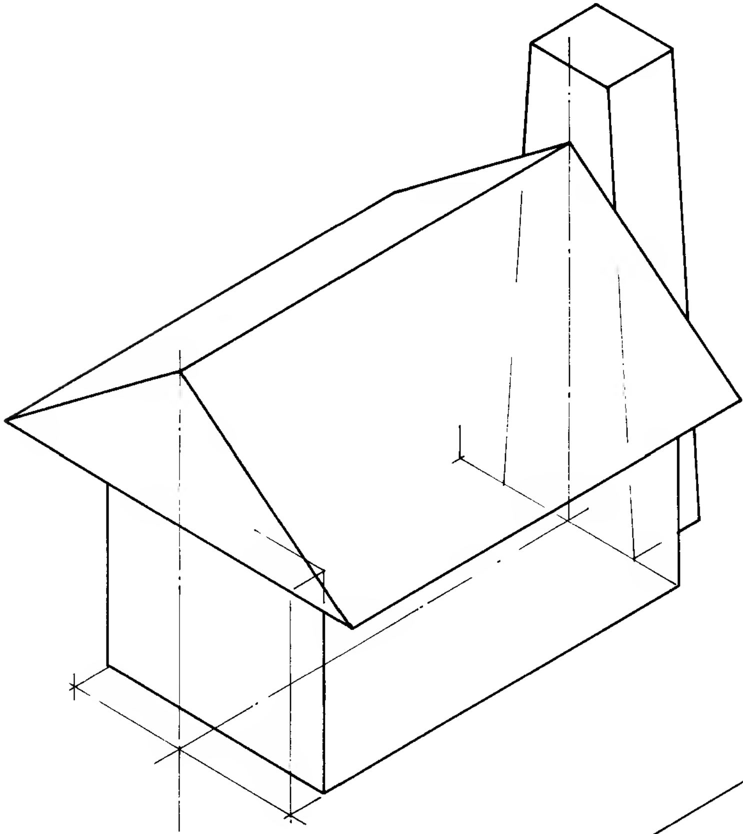
FIG 62

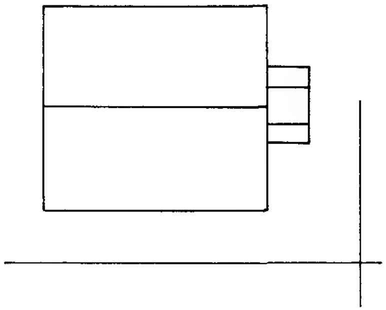


FIRST ANGLE



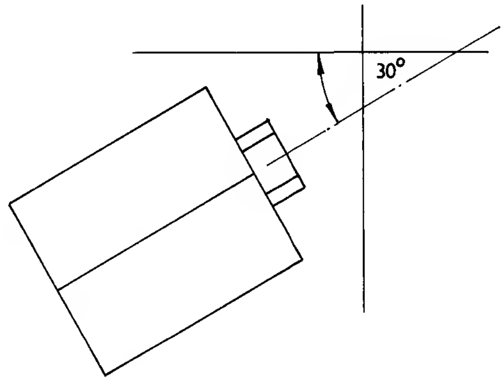
FIRST ANGLE





THIRD ANGLE

FIG 63



FIRST ANGLE

Hidden detail on orthographic views

When presenting orthographic views two types of line are generally used: full bold lines to show visible edges; and dotted lines to show detail which is not visible—hidden detail.

When preparing orthographic drawings all visible detail must be shown, even if it is presented on other views. No such precise statement, however, can be applied to hidden detail and in practice it is left to the discretion of the draughtsman to insert sufficient hidden detail to allow a clear and correct interpretation of the drawing.

Young people, whose experience is limited, often find difficulty in the placing of hidden detail, and consequently the object may be inadequately represented. If, however, all hidden detail is shown on all views, the result will be a confused drawing which is very difficult to read. This difficulty may be overcome by precise instructions regarding the amount of hidden detail required on the solutions. On simple drawings all the hidden detail may be shown: on drawings of a more complex nature, though all hidden detail is considered, that which will confuse the drawing should be omitted.

Sectional views

The use of dotted lines on a view to indicate an internal profile may well prove confusing unless the internal form of the component is very simple. Should the internal form be complex, the component may be cut in such a way as to expose the internal profile, and this exposed detail, otherwise shown by a dotted line, will now be indicated by a full line. Such a view is called a section, and the component is said to have been cut by a section plane. Material which has been cut by this plane is cross hatched at 45° with thin lines.

The section plane is indicated on one of the orthographic views by a bold chain dotted line, arrows on the end of which dictate the direction in which the section view is to be projected. A sectional view should always be titled.

Half section

When objects that are symmetrical are dealt with, one half may be drawn as it would appear if cut by a section plane, while the other half is shown as a normal view of the exterior. It is usually considered unnecessary to show on the full half details shown on the sectioned half.

Part section

Where the internal detail of a component is relatively small compared with the component itself, it may be sufficient to section this part of the component only: it is then referred to as a part section.

Revolved and removed sections

When a simple transverse section of a component is required, the section may be revolved and superimposed on the view concerned. If, however, there is insufficient room to revolve and superimpose the section, it may be removed and placed adjacent to the view it describes.

Staggered section

In this, as the name suggests, the section plane is staggered and is used to bring into sectional view internal detail which would not be revealed if the component were cut by a single section plane.

Sectional trace

This section is the profile of the cut face only: the trace of the component on the section plane.

Exercise

Using selected examples from the previous pages, prepare several sectioned plans and elevations, together with their respective elevations and plans.

Drawing procedure

Drawings should be clean, neat and accurate, and completed in a reasonable time. A clear thinking and orderly approach is essential if good results are to be achieved. Time spent in planning the layout of the drawing will be time well spent, and will avoid unnecessary frustrations that arise when drawings are ill placed on the paper. The following suggestions of procedure will enable a degree of confidence in the presentation to be enjoyed and a pleasing result obtained.

All drawings should be presented on a suitable format: suggestions are offered in the appendix, one for a horizontal sheet and a similar one for a vertical sheet. The use of a suitably designed rubber stamp for a title block would save much valuable drafting time and a simple device to register the position of the paper and the application of the stamp itself would prove to be an interesting design topic.

1. *Decide on a suitable layout*. On a separate piece of paper sketch suitably dimensioned rectangles to contain each view. This will enable their positions to be arranged on the drawing paper in a pleasing and intelligent way.
2. On the drawing paper itself *insert centre lines* or datum edges *on all views*.
3. Draw in *lightly* and project the required views of the object; try to build up the views together. This method of working is quicker and to be preferred to the completion of individual views. *Stroke* on the lines using a fairly hard pencil, say 4H. The choice of pencil will depend on individual preference.
4. *Line in* with good quality lines *all arcs and circles*. It is easier to join a line to a circle or an arc than *vice versa*. It is also easier to control the density of a straight line.
5. *Line in all horizontal and vertical lines*, using a softer pencil, say H, pressing more firmly, and maintaining a good sharp pencil. When lining in do not over shoot, especially at corners. Great care must be exercised when lining in: the cusp formed by a reasonably hard pencil is difficult if not impossible to remove.
6. Insert dimensions, section lines and any other relevant details.

Geometric solids

These solids can present some interesting problems in technical drawing. They may be considered singly or in groups, two or three solids together. Both very simple and complex drawings may be developed from them.

Definitions of solids

A solid formed by many plane faces is called a *polyhedron*. A *regular polyhedron* is formed if each face is a regular polygon, and the angles formed between the faces are equal.

There are only five regular polyhedra and they are sometimes referred to as the platonic solids.

The *regular tetrahedron* has four equal faces, each an equilateral triangle.

The *cube*—six equal faces, each a square.

The *regular octahedron*—eight equal faces, composed of equilateral triangles.

The *regular dodecahedron*—twelve equal faces, composed of regular pentagons.

The *regular icosahedron*—each of the twenty faces an equilateral triangle.

A *prism* is a solid whose ends are congruent and parallel polygons, and whose sides are parallelograms.

A *pyramid* has a regular polygon for its base and its triangular sides have a common vertex.

A prism and pyramid are said to be *right regular* if the base is a regular polygon and the axis is perpendicular to the base. If the axis is inclined, the solid is referred to as *oblique*.

A *cylinder, cone and sphere* are *solids of revolution*.

A *cylinder* is generated by a *rectangle* revolving about an edge.

A *cone* is generated by the revolution of a right-angled triangle about one of its sides containing the right-angle.

A *semi-circle* revolving about its diameter will generate a *sphere*.

Problems involving the use of these solids are usually interpreted from written information, and the solids are often referred to as prism, pyramid, cone and cylinder, and right regular is implied.

The orthographic projection of solids

It is desirable in the first instance to draw the solid in a simple position, that is, with its base parallel to one of the planes of reference. From this simple plan and elevation other projections may be determined.

This method is demonstrated in the following examples.

Exercises

Complete three views of the solids shown in Figs. 64, 65, 66 and 67. A 10 mm grid has been used to facilitate the positioning of the solids. The cylinder is 40 mm dia × 60 mm, the square prism 30 mm × 30 mm × 80 mm—and the height of the triangular prism is 50 mm, its length of side 35 mm. Modifications may be made, but the corresponding projections must be correct. Several of the examples call for a sectional elevation. All solids in the views shown are touching the horizontal plane; those in Figs. 64, 65 and 66 are in the first quadrant and that in Fig. 67 is in the third quadrant.

After completing these examples, attempt the following.

A hexagonal prism, edge of base 25 mm and 65 mm high, stands on the horizontal plane with an edge of the base inclined at 45° to the vertical plane. Determine a sectional elevation by a plane parallel to the vertical plane and containing the axis of the prism.

Draw the plan of a hexagonal pyramid with a slant edge vertical, edge of base 30 mm height 75 mm.

Determine the plan of a tetrahedron with one edge vertical, length of edge 60 mm.

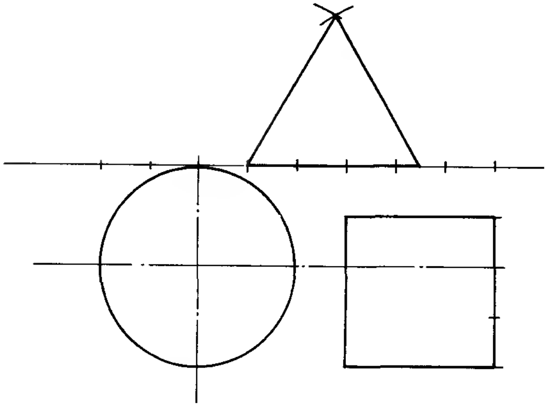


FIG 64

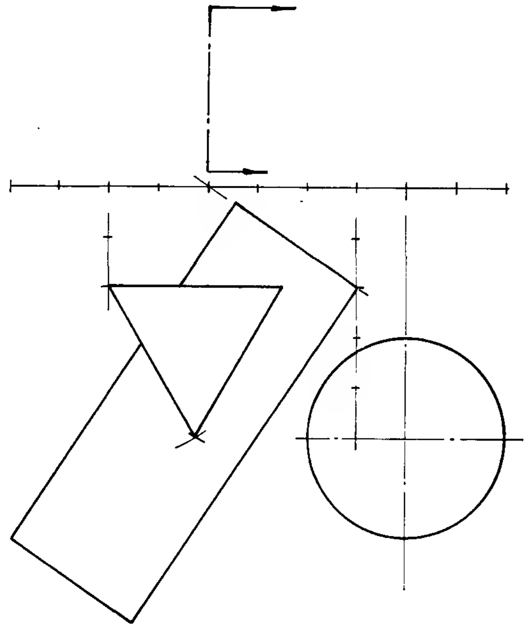


FIG 65

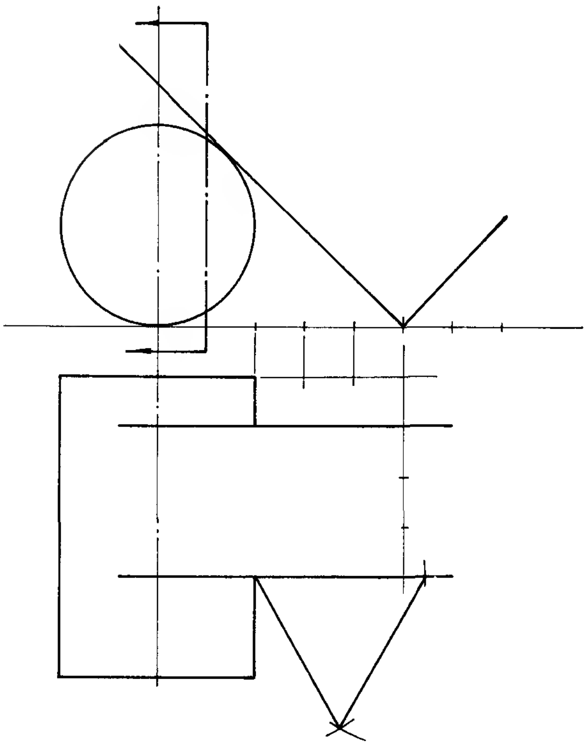


FIG 66

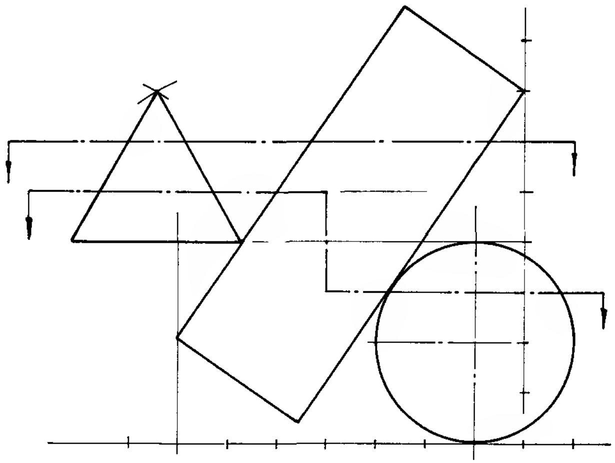


FIG 67

Geometric solids (continued)

The isometric drawing (Fig. 68) is a splendid example of a technical drawing model, which, if used imaginatively, can be developed in many ways.

Models such as the one shown may easily be made and if they are to be used for direct measurement they should be dimensionally accurate. A steam roller or a tractor could be used similarly, all their several components being composed of simple solids.

Exercise

1. Prepare an orthographic drawing of the lorry shown in Fig. 68. Measurements may be taken directly from this drawing. Datum and centre lines have been selected to facilitate easy measurement.

This example may be followed by any of the examples suggested below, or any others that may come to mind using this basic example:

2. *The lorry as a tip-up truck.* The truck elevated to 60°.
3. *The lorry transporting a large cable drum*—say 60 mm dia × 25 mm or *2 reels of news print*—35 mm dia × 40 mm.
4. *The lorry as a petrol tanker*: the truck body mounted on the chassis behind the cab is to be removed and replaced by a large cylindrical tank 40 mm diameter.
5. *The lorry as a BOC liquid gas transporter*: the truck body is to be removed and replaced by a large sphere (50 mm dia) mounted centrally on the chassis.

What is the temperature of liquid oxygen?

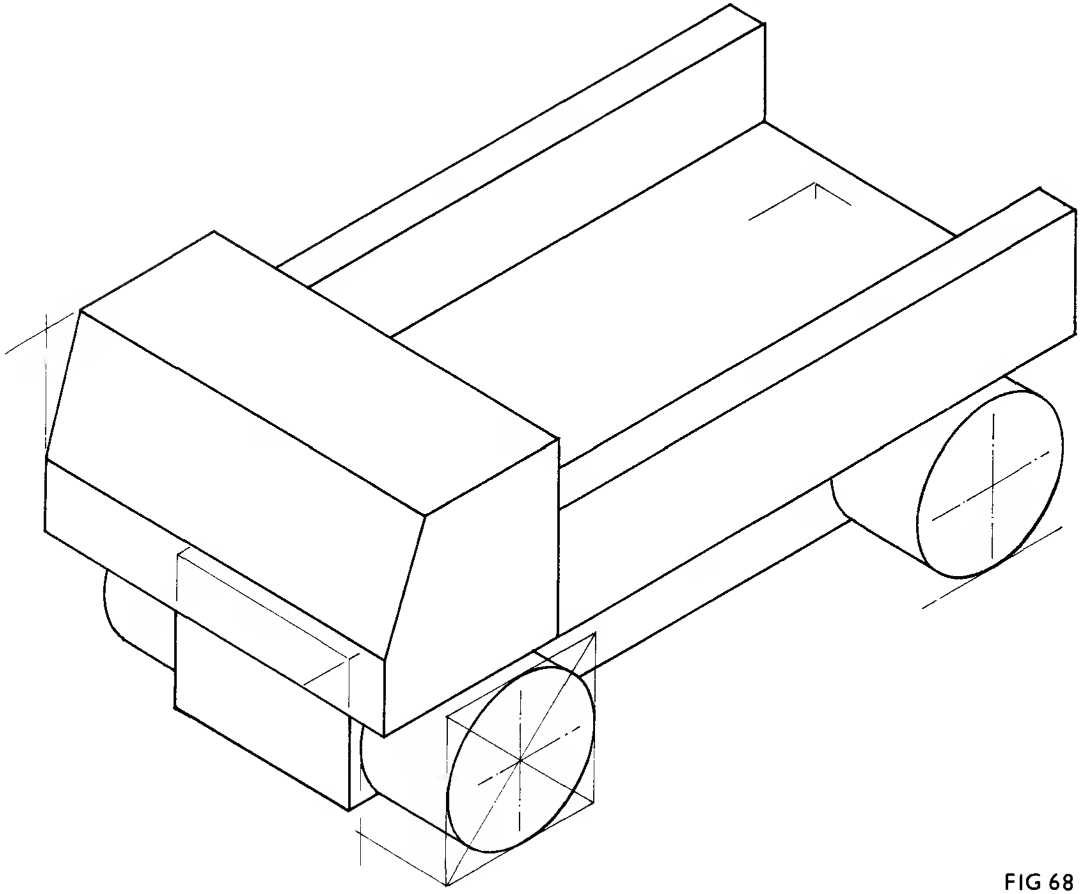


FIG 68

Pictorial projections

A pictorial projection is a projection which displays all three dimensions and presents a pictorial view. These projections may be considered in three main groups, *perspective*, *oblique*, and *axonometric* and these may be further sub-divided.

Perspective drawings produce excellent pictorial views and, although much interesting work can be undertaken using this method, it is a very specialized technique practised mainly by technical illustrators, architects and artists. There are several text books available dealing with this type of pictorial projection only.

Oblique—This method presents one true elevation and the projectors to the picture plane are oblique, usually inclined at 45°, and often the dimensions along the oblique lines are halved.

Axonometric projection is an orthographic method of pictorial drawing. The projectors are perpendicular to the picture plane. There are three types of axonometric projection, dimetric, trimetric and isometric.

Isometric is a projection where all the dimensions are equally fore-shortened, and while the other methods may present a more balanced view, this method commends itself by its simplicity and will be dealt with in detail.

Isometric projection

If a cube be arranged in such a way that all its edges are equally foreshortened, the orthographic projection on the picture plane will show an *isometric projection* of a cube.

Consider its movement in two stages.

1. With its bottom face resting on the horizontal plane and its vertical faces inclined at 45° to the vertical plane the front elevation records a foreshortening of all the horizontal edges, but the vertical edges remain unaltered (Fig. 69).

2. If the cube is tilted about the bottom front corner until the body diagonal is horizontal, the front elevation will show all edges equally foreshortened, and *this view is the isometric projection of the cube*. The angles of inclination of the adjacent faces of the front elevation may be readily drawn using a 60/30° set-square without first drawing the orthographic views and projecting from them (Fig. 69).

It is often convenient to ignore the foreshortening and to draw the isometric view to the natural size. It is evident that in the majority of cases this will have no serious effect upon the view; it will display a slightly larger view only.

When an object which includes a sphere is drawn, all dimensions are foreshortened, except those of the sphere, the diameter of which always appears the same irrespective of the position from which it is viewed. The isometric scale must therefore be used in this special case.

The choice of position of the object to be drawn should be such that the most comprehensive view will be displayed. Hidden detail is usually excluded as it tends to destroy the pictorial value of the view.

Fig. 69 shows the development of the isometric cube. Fig. 70 displays a method which may be used to project an isometric drawing from a suitably inclined plan and elevation.

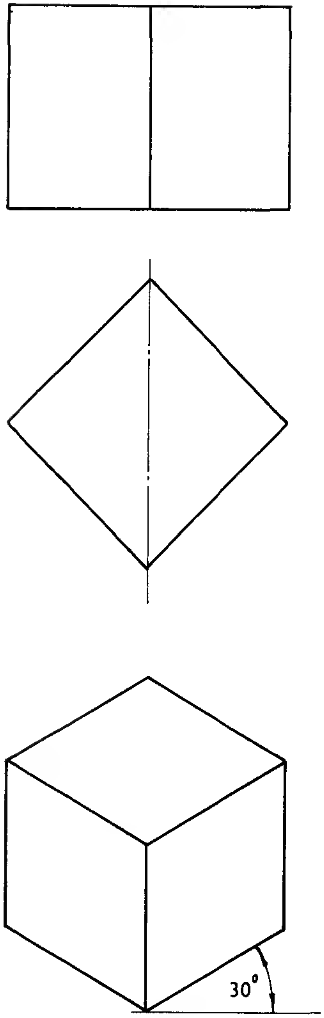


FIG 69

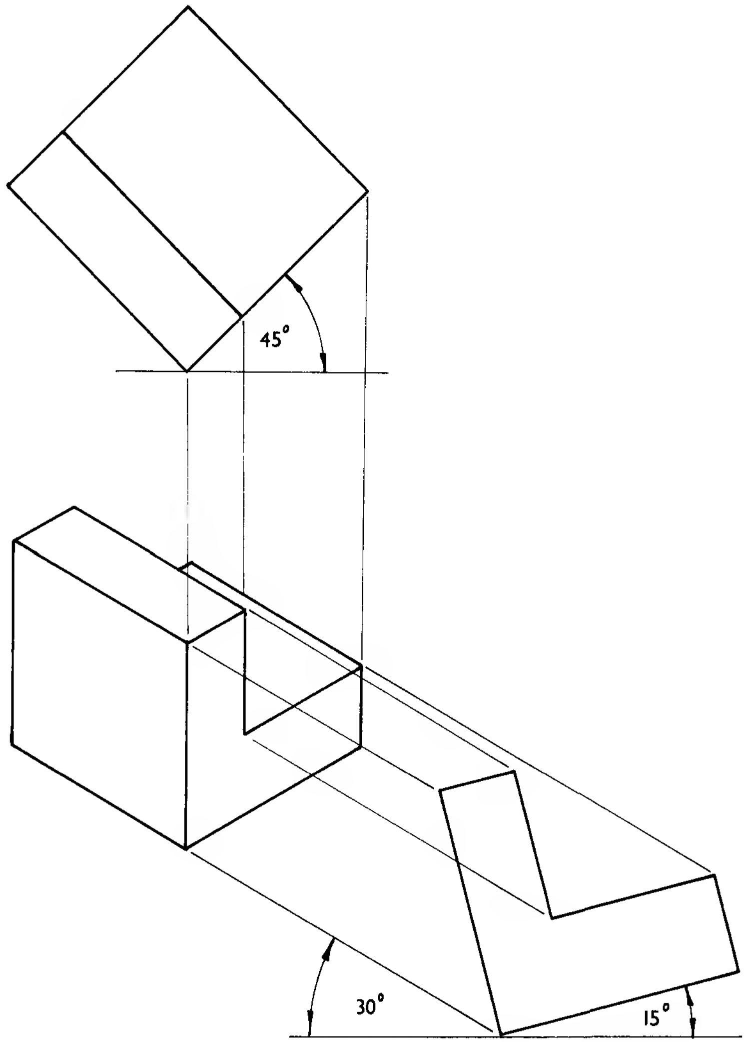


FIG 70

Isometric projections

The isometric projection of circles and irregular figures

It is often necessary to draw a circle in isometric projection and this may be achieved in one of several ways.

1. Consider first of all a circle inscribed in a square (Fig. 71). The square, turned about its horizontal axis, is shown on the side elevation. The sides of the square now presented in the front elevation are foreshortened and inclined at 30°. This is called the *isometric square* and the circle now appears as an ellipse, the major axis of which is equal to the diameter of the inscribed circle. The foreshortened diameter of the circle, the minor axis, is projected from the side elevation.

From this drawing it is also interesting to note that the *true length*, and the *foreshortened length* of the side of the square, form the basis of the *isometric scale*. The angle on the side elevation shows the angle through which it must be turned to give the *isometric square* in the elevation.

Several methods are available for the drawing of the ellipse but whichever method is chosen it is always advisable to draw the isometric square first.

The first method, the *trammel method*, has previously been described. A simple diagonal scale will give the semi-minor axis if the semi-major axis is known. This scale could be drawn on a piece of white card and used for all isometric drawings of circles.

The *approximate method of arcs does not produce a true ellipse*. It readily produces an acceptable result, and can be used only within an isometric square.

The use of a *template* greatly facilitates the speed and quality of the drawing of small ellipses. Special templates for the drawing of isometric ellipses are available. All ellipses are projected from a plane inclined at 35° 16′.

2. The *method of ordinates* is a straight-forward method used to determine the isometric projection of irregular figures, or circles. A quadrant is used to demonstrate this method in Fig. 72. It is necessary to divide the elevation by a number of ordinates conveniently spaced and cutting the salient features of the object. An isometric square or rectangle is then prepared containing the ordinates previously selected, and it is along these ordinates that the corresponding vertical distances, taken from the elevation, are marked.

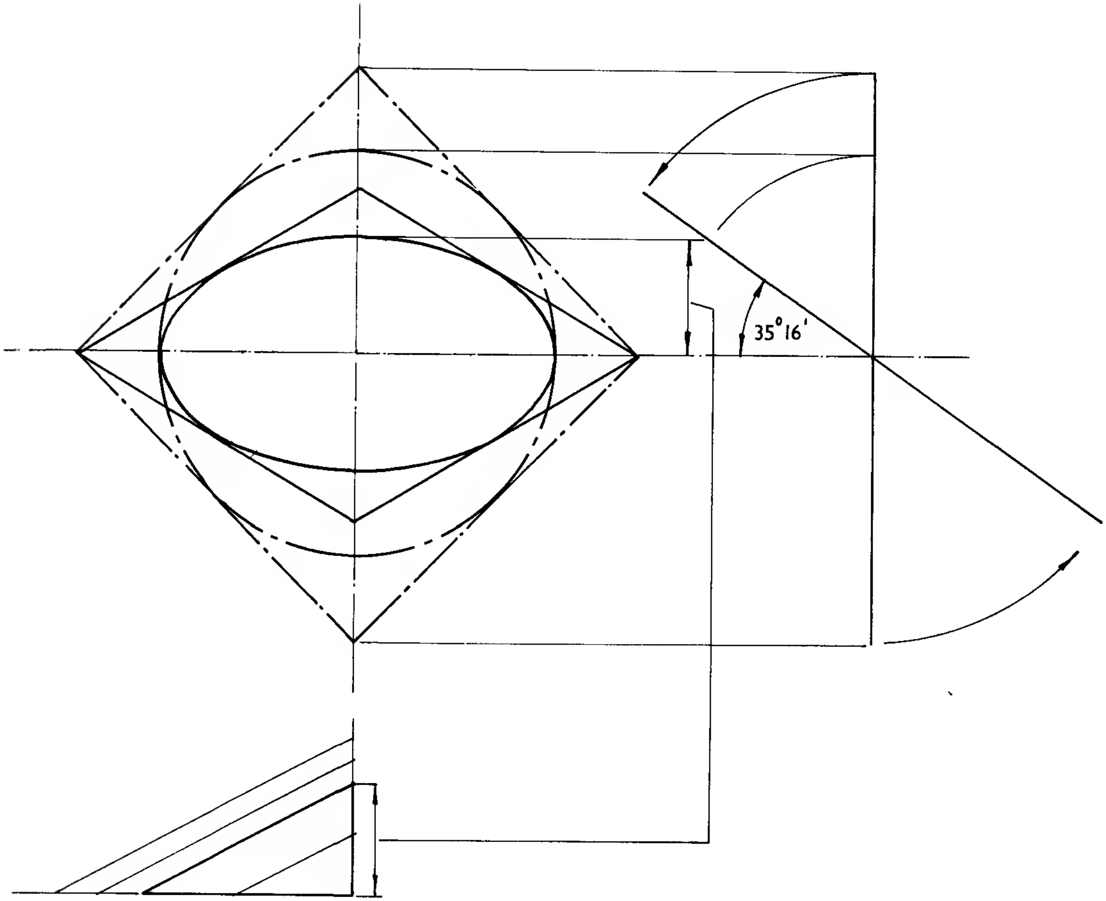


FIG 71

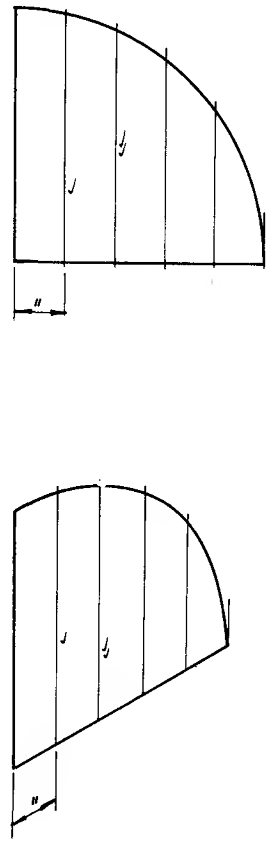


FIG 72

Isometric projections (continued)

Exercises

Fig. 73 presents some examples to be attempted. The drawings are marked in increments of 10 mm.

Using isometric detail paper sketch free-hand some of the drawings shown in Figs. 62 and 63 from another point of view.

Draw in isometric projection the following:

A hexagonal prism, length of side 40 mm height 30 mm.

A cube of 50 mm side, on the top of which is a sphere of 50 mm diameter. (The axis of the cube passes through the diameter of the sphere.)

A hemisphere of 80 mm diameter.

More complex isometric projections may be derived from the drawing developed from Fig. 68.

The plan and elevation may be cut from one of your drawings and suitably placed on a sheet of drawing paper, and an isometric view obtained by projection as shown in Fig. 70. Alternatively the views may be re-drawn or taken from your drawing on detail paper.

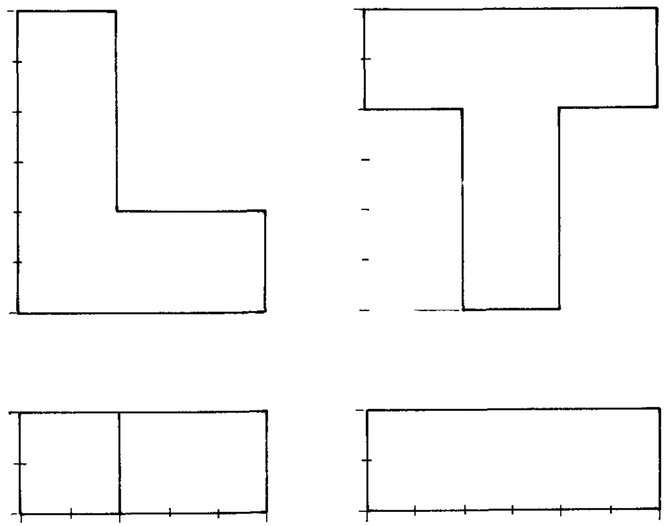
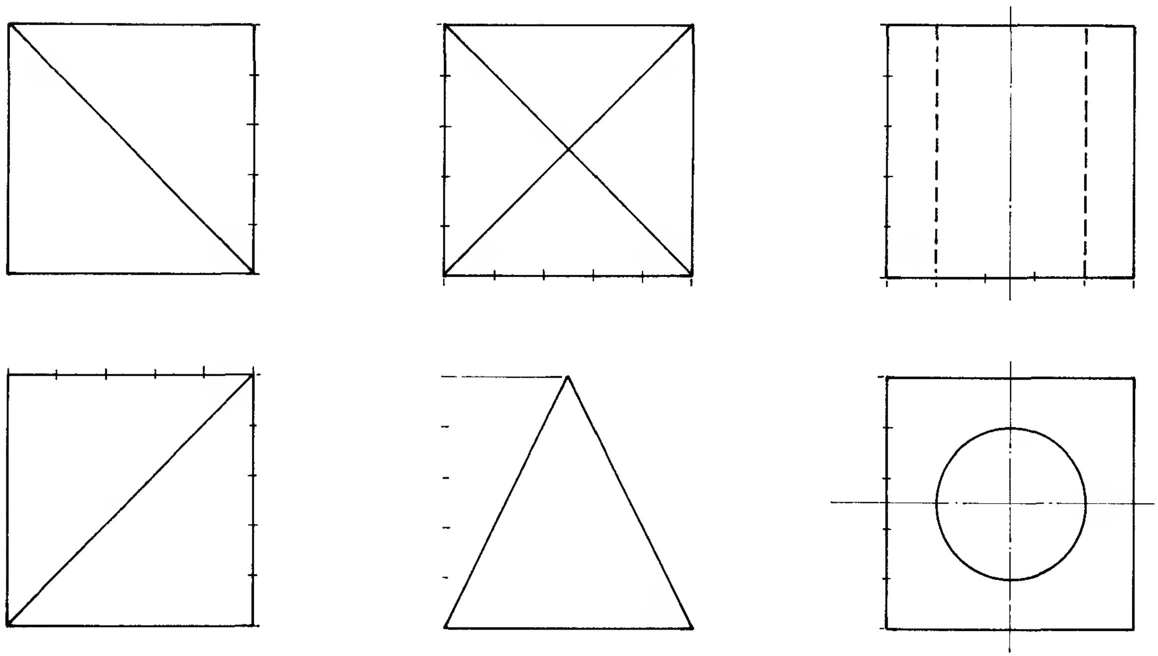


FIG 73



E

Auxiliary projection

Auxiliary views are sometimes necessary in technical drawings to give information that cannot readily be shown in the normal plan and elevation. It is generally an additional projection which augments the information given by the principal views.

Auxiliary projections also facilitate the solution of problems in descriptive geometry and enable more complex projections of objects to be undertaken.

Consider the drawings on the adjacent page.

1. Fig. 74 shows a series of *auxiliary vertical planes*. The *traces* of these planes will be lines and will be where the plane touches the horizontal and vertical planes. The traces in this example are represented by a vertical line on the vertical plane, and by a line inclined to the *xy* line on the horizontal plane. The dividing line between the horizontal and the *auxiliary* vertical plane will also be an *xy* line, a dividing line between horizontal and vertical planes. Any projection from a plan onto this plane will result in an *auxiliary elevation*.

It can readily be seen that the only *xy* line where the AVP can be opened out through 90° will be with the horizontal plane. This fact will determine whether the projection will be a plan or elevation. In dealing with problems of this nature a small free-hand pictorial sketch is most helpful, or a piece of folded card used as a model.

2. Fig. 75 shows a series of *inclined planes*, planes inclined to the horizontal. It is clear that the traces formed by the introduction of this plane will be *normal*, or at right-angles to the *xy* line on the horizontal plane and inclined to the *xy* line on the vertical plane. In this instance the *new xy* line chosen will be the one represented by the trace on the vertical plane, the only line through which the planes can be opened out through 90°.

Any projection from an elevation onto this plane will result in an *auxiliary plan*.

An *auxiliary elevation* is a projection on to any *auxiliary vertical plane*. (AVP)

An *auxiliary plan* is a projection on to any *auxiliary inclined plane*. (AIP)

When dealing with auxiliary projections, it is helpful to remember that

(i) the projection of a point on the plan to a corresponding point on the elevation is always perpendicular to the *xy* line, and

(ii) the distance of a point on any elevation, or plan, is equal to that from its corresponding *xy* line.

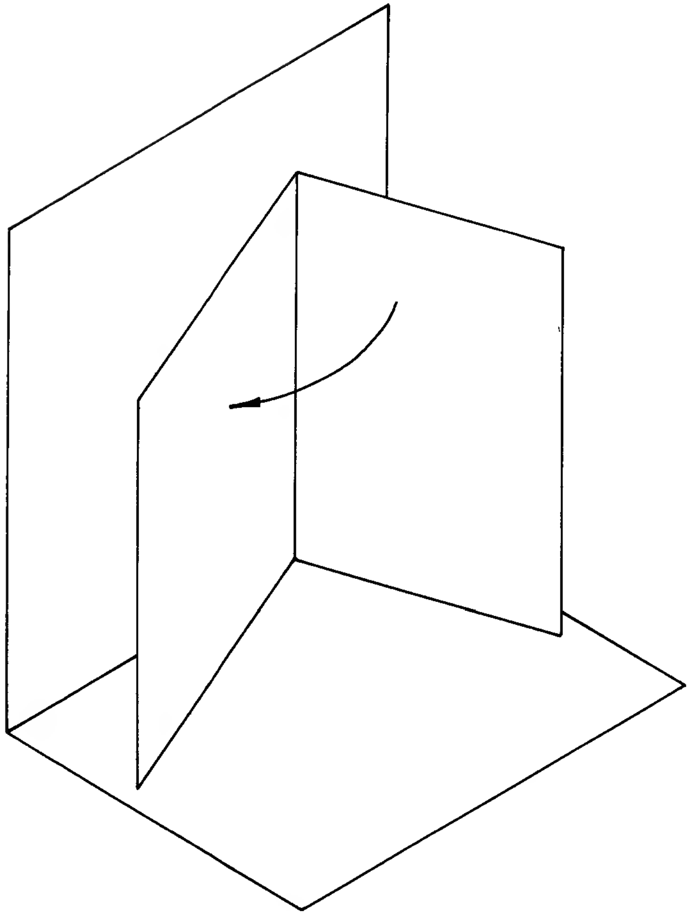


FIG 74

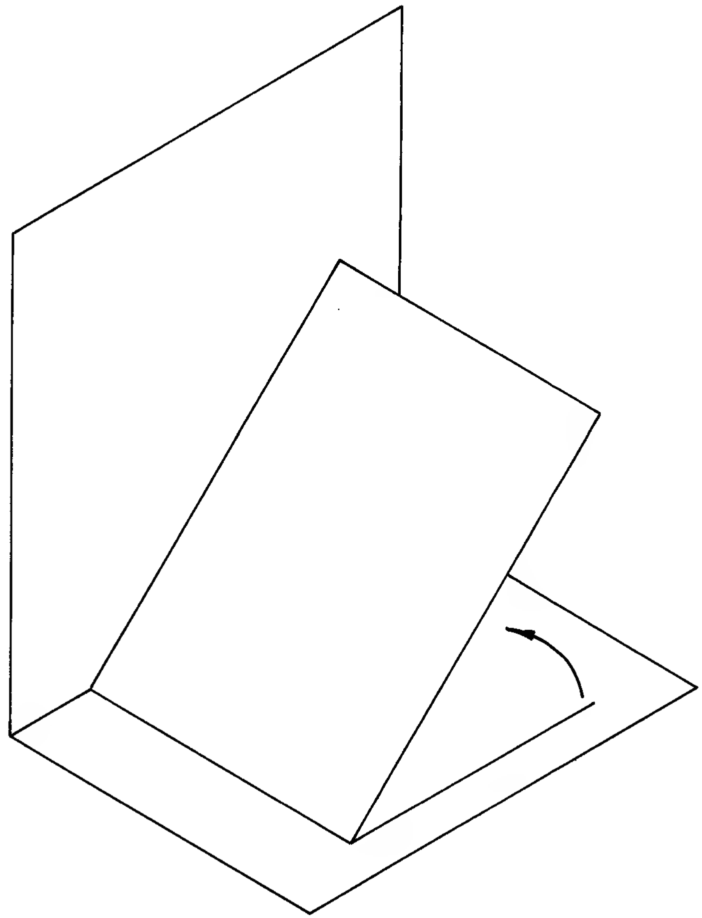


FIG 75

Auxiliary projection (continued)

Fig. 76 shows the development of an auxiliary plan and elevation from a simple angled bracket.

Exercises

A cube of 80 mm edge has one face on the horizontal plane and another inclined at 30° to the vertical plane. Draw its elevations. Project also an auxiliary elevation on a line making 45° with the *xy* line and an auxiliary plan making 60° with the *xy* line.

An hexagonal prism has a face resting on the horizontal plane and an edge of the base is inclined at 60° to the *xy* line. Determine a sectional elevation by a given auxiliary plane which is parallel to the vertical plane and 50 mm from it. The edge of the prism is 25 mm, its length 60 mm, and the prism touches the vertical plane.

A pentagonal pyramid, edge of base 30 mm height 70 mm, stands with its base on the horizontal plane with an edge inclined at 30° to the vertical plane. Draw its projections. Draw an auxiliary plan of the pyramid on a line making 60° with the *xy* line.

An hexagonal pyramid, 60 mm across the flats, slant height 90 mm, is truncated by a cutting plane inclined at 45° to the horizontal plane which enters the pyramid 20 mm above the horizontal plane.

Draw the plan, elevations and a view normal to the cutting plane. State the name given to the projection which is normal to the cutting plane and describe the shape of the cut face in this view.

When the projection is normal to the cutting plane and shows *only* the cut face, the projection is said to be a *sectional trace*.

Draw the auxiliary projection of a cube of 50 mm side, normal to its body diagonal. This projection will be the isometric projection of a cube; the body diagonal will appear as a point.

Auxiliary projections of a more complex nature may be developed using the group of solids in Figs. 64–67.

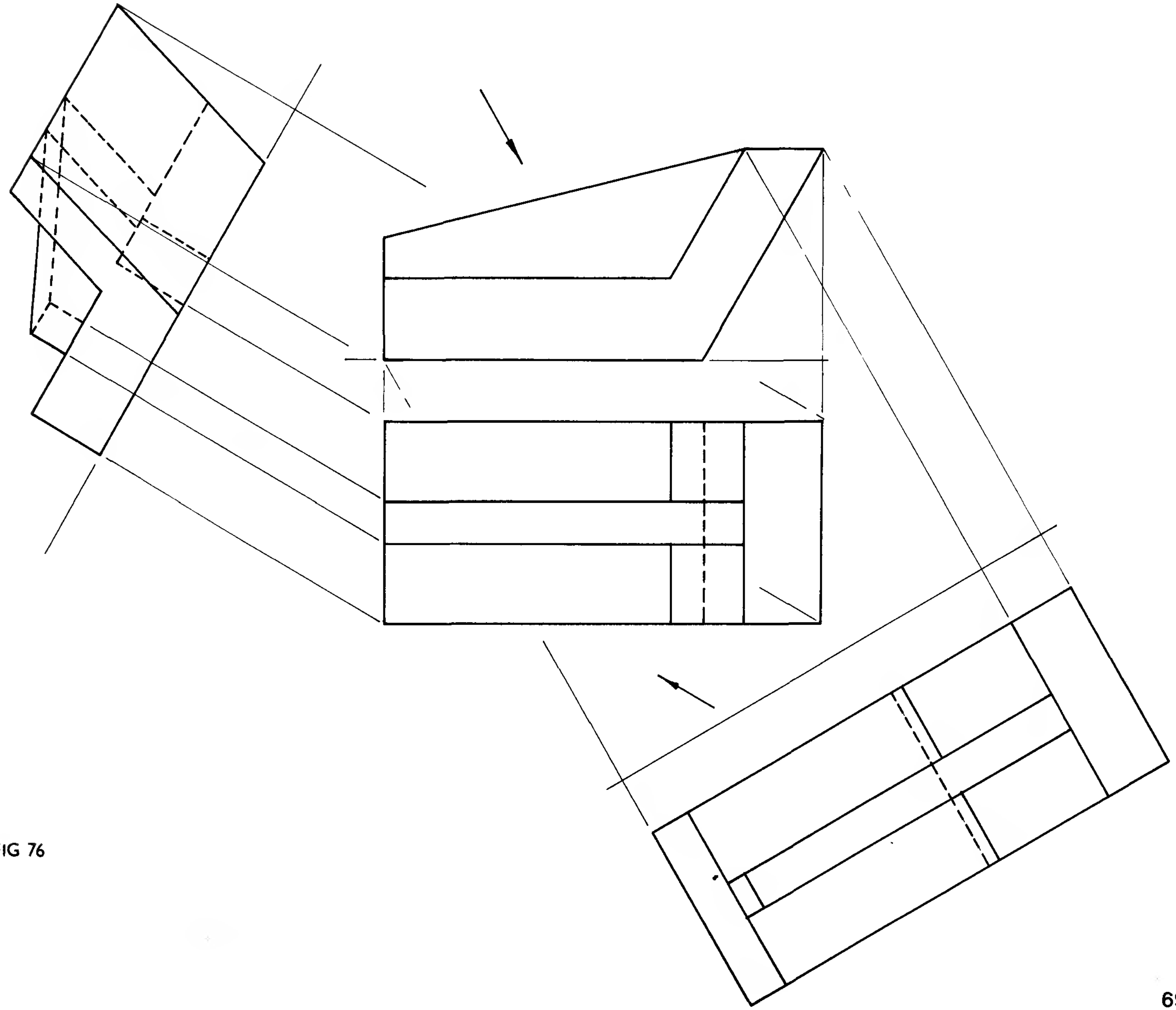


FIG 76

Auxiliary projection (continued)

Auxiliary projections also facilitate the solution of problems in descriptive geometry: the example shown in Fig. 77 demonstrates how an auxiliary projection may be used to determine the true shape of a plane area.

Select a cutting plane parallel to the horizontal plane and passing through a corner of the triangle. It is possible by projection to establish that this plane will intersect the opposite side of the triangle at *a*. If a view is now taken normal to this "line", an auxiliary elevation will result showing the triangle or plane area as a line. A further projection normal to this line will reveal the *true shape* of the triangle and a second auxiliary plan.

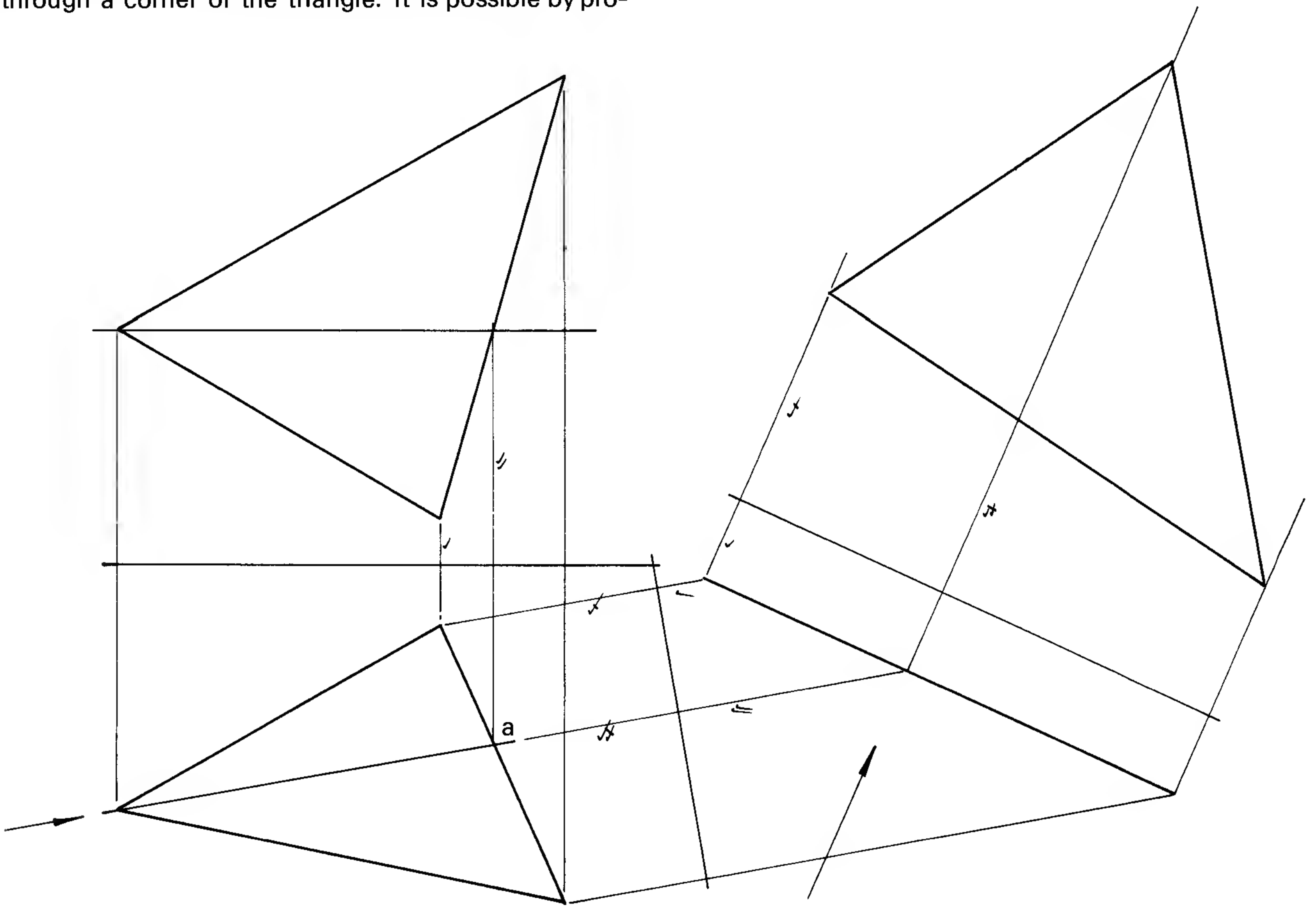


FIG 77

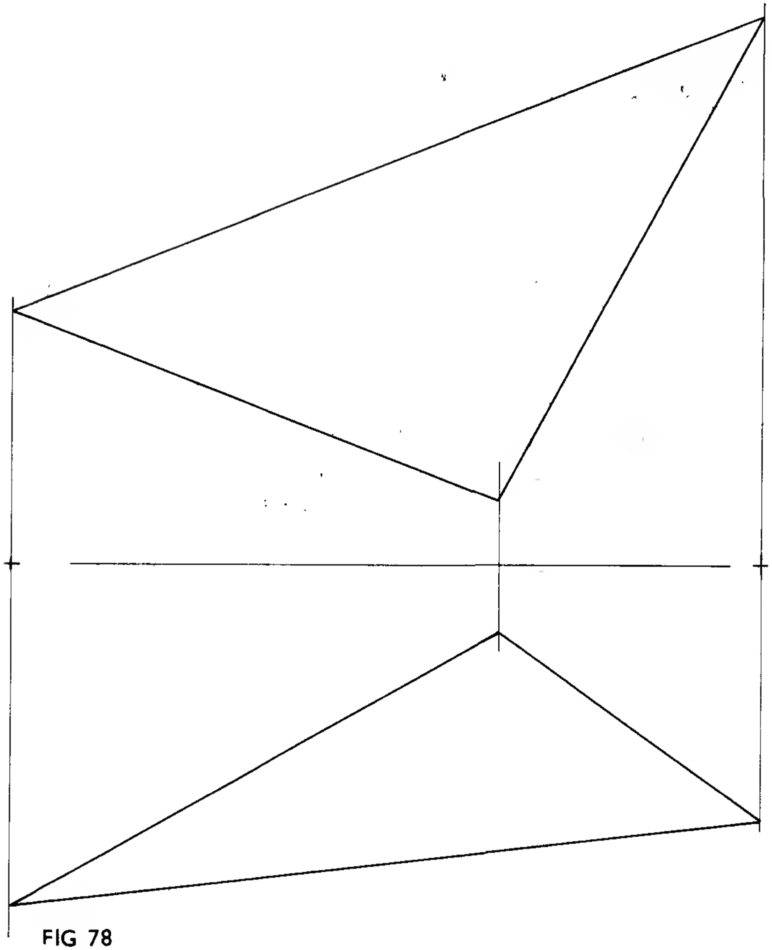


FIG 78

Exercises

Determine, by projection, the true shape of the triangles shown in Figs. 78 and 79. These examples may be taken from the book on detail paper, with a compass onto cartridge paper, using the salient points marked on the *xy* line, or they may be pricked through. These methods will save much valuable time.

These simple examples readily demonstrate auxiliary projection, the solutions necessitating clear thinking and an orderly approach. The examples also demonstrate a true understanding of orthographic projection.

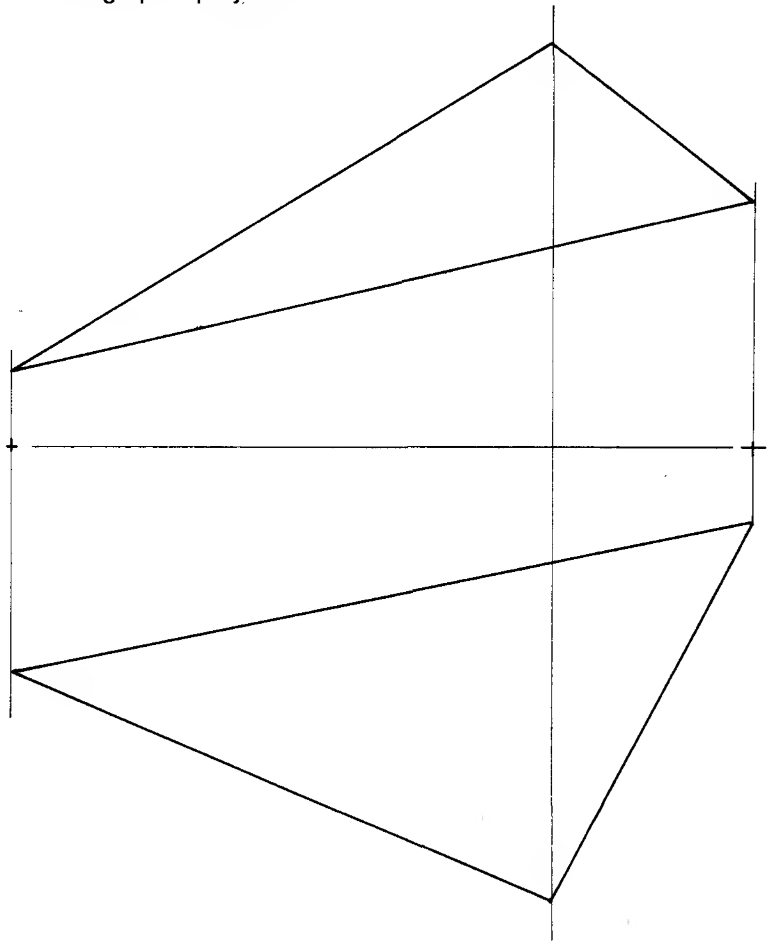


FIG 79

Dihedral Angle

The angle that is bounded by two planes and measured normal to them is called the *dihedral angle*. Several examples come to mind: the dihedral angle between the horizontal and vertical plane is 90°, the dihedral angle of a roof, or contained in the corner of the forge-hood, the corner of a steel wheel barrow, or a pyramid.

Consider the two planes shown diagrammatically at the top right of the adjacent page (Fig. 80) and the main projection which is an orthographic representation. The traces of the planes are shown, two on the horizontal and two on the vertical plane. Also shown on the plan is the corner or intersecting line of the two planes. The *dihedral angle* is the angle formed by these two planes and may be considered as the angle at the apex of a triangle which is normal to the line of intersection of the two planes and whose traces on each plane will also be normal to the line of intersection.

Consider a cutting plane which will satisfy these conditions: a plane which will be normal to this line, representing the edge of both planes, in the plan and elevation. The trace that the cutting plane will form on the horizontal plane will be normal to the corner of the two planes and is shown on the plan by TCP (trace of the cutting plane).

Consider now in the elevation a view normal to and containing the corner, that is to say, an elevation showing the true length of the corner. It is also possible to establish where the trace of the cutting plane touches the horizontal plane (*a* in the plan, a_1 in the elevation). This cutting plane will be normal to the corner and will pass through the point *a*. With *cd*, the base of the triangle on the plan, mark from a distance a_1b the perpendicular distance from the horizontal plane to the corner, the intersection of both planes. The triangle so fo[illegible] the *dihedral angle*.

Exercises

Draw two planes, similar to those shown in Fig. 80, and determine the dihedral angle. Then draw on the plan, with the aid of a pair of compasses to mark off corresponding lengths, two triangles representing the two intersecting planes. Using an Ever Ready razor blade against a steel rule, cut along the lines marked *c* and fold along the lines marked *f*. This model, when folded, will show the dihedral angle. (Use cartridge paper for this example. A piece of coloured card stuck to the cartridge paper could be used for the triangle containing the dihedral angle, and for a right-angled triangle, shown shaded, to locate the position of the triangle containing the dihedral angle. It also shows it to be normal with the corner or edge of the plane.)

The dihedral angle may also be determined by *auxiliary projection*. Using this method and the model, if needed, determine by drawing the dihedral angle between the side and the front of an extraction hood over a furnace, which has the following dimensions: bottom 800 mm long, 600 mm wide, vertical height 600 mm, outlet at the top 500 mm long 250 mm wide. It is only necessary to consider one corner. Use a suitable scale. This is a good example where auxiliary projection may be used to solve a problem quickly and effectively: a partial solution is shown in Fig. 81. The first projection from the plan shows the triangle containing the dihedral angle as a line: the edge view of the triangle. A view projected normal to this triangle will show the dihedral angle. The view of the edge of the two planes is a point.

The examples overleaf are also interesting examples of auxiliary projections. Figs. 82 and 83 determine the true shape of the sloping face, and Fig. 84 is an exercise involving several auxiliary projections, the solution of which will show a true understanding of orthographic projection.

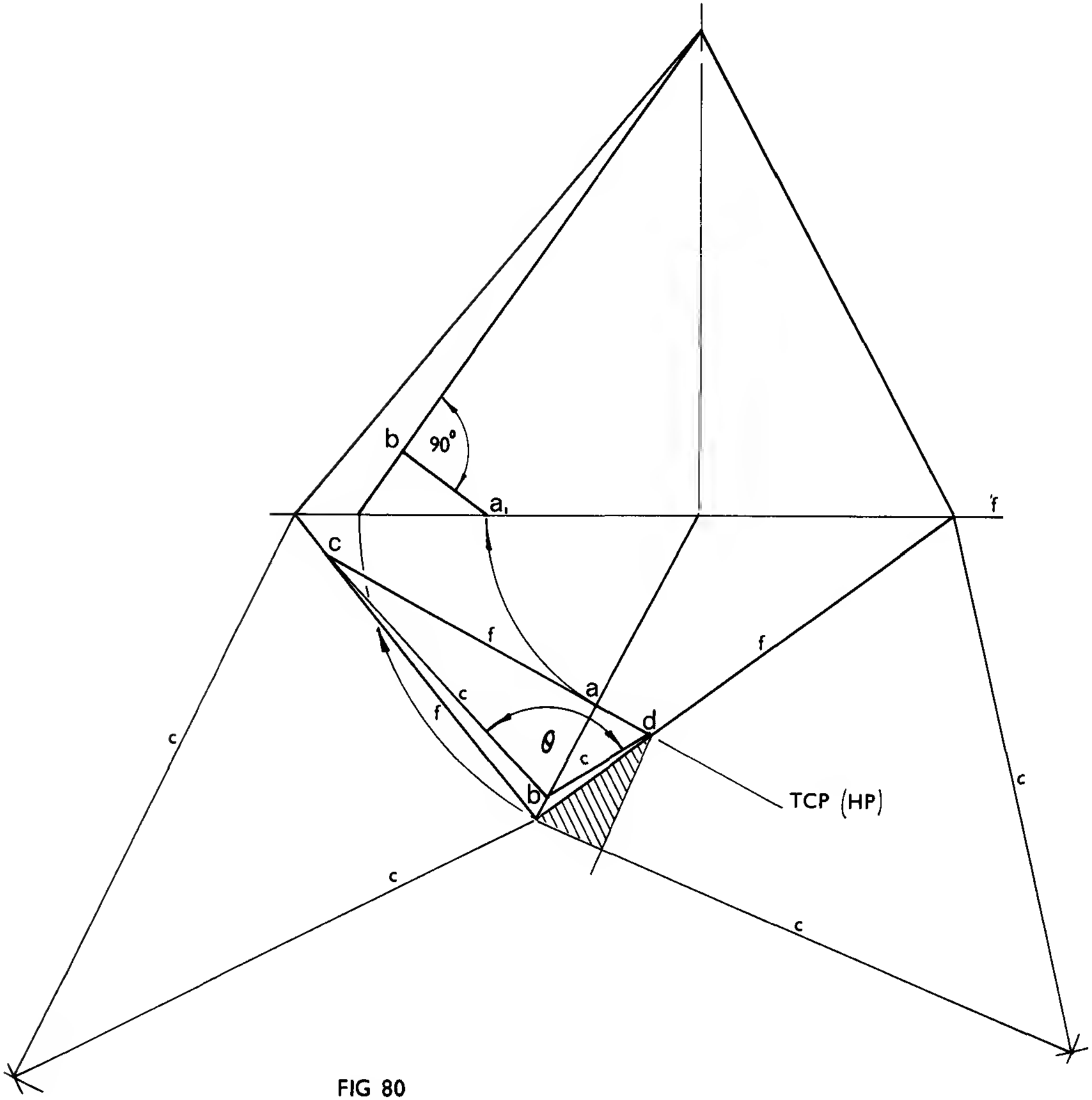
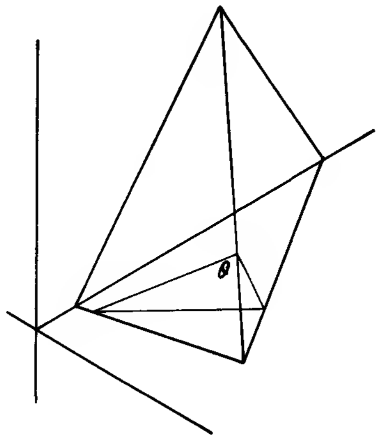


FIG 80



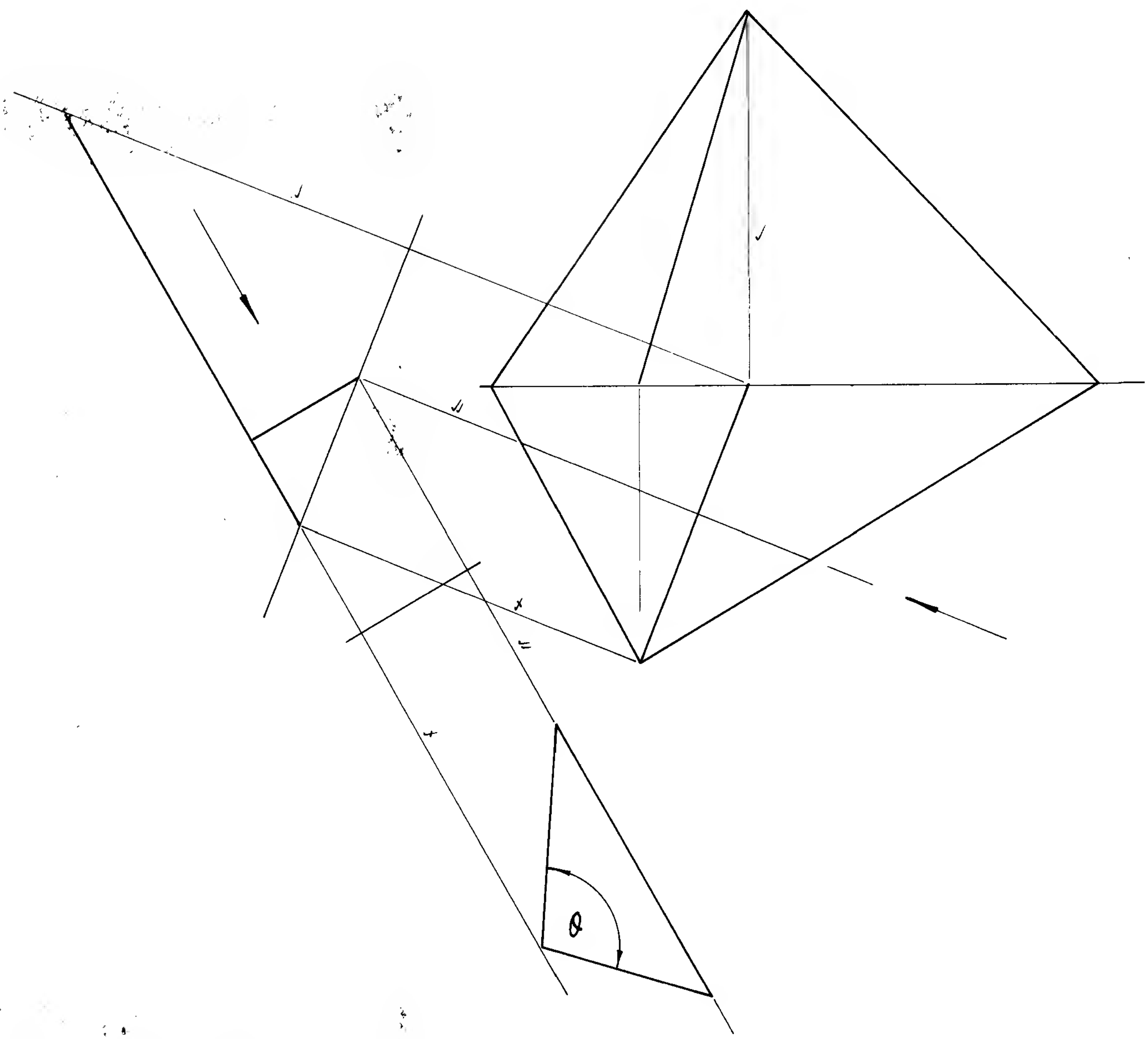


FIG 81

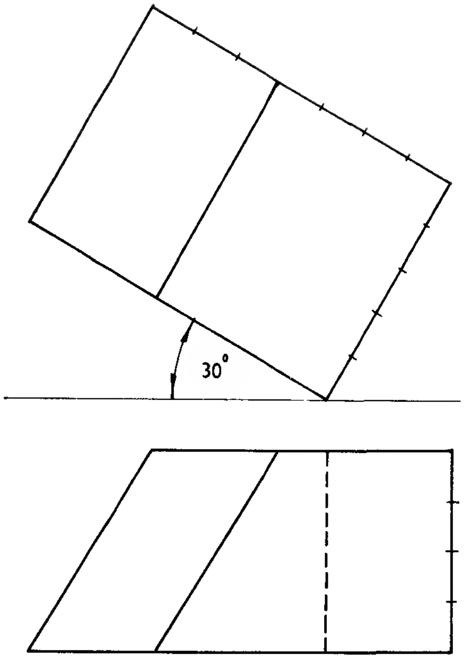


FIG 82

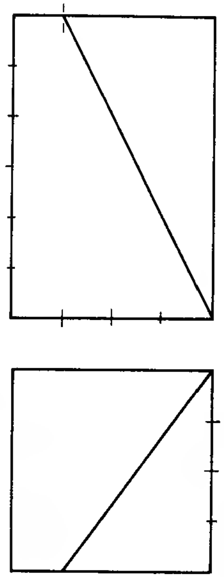


FIG 83

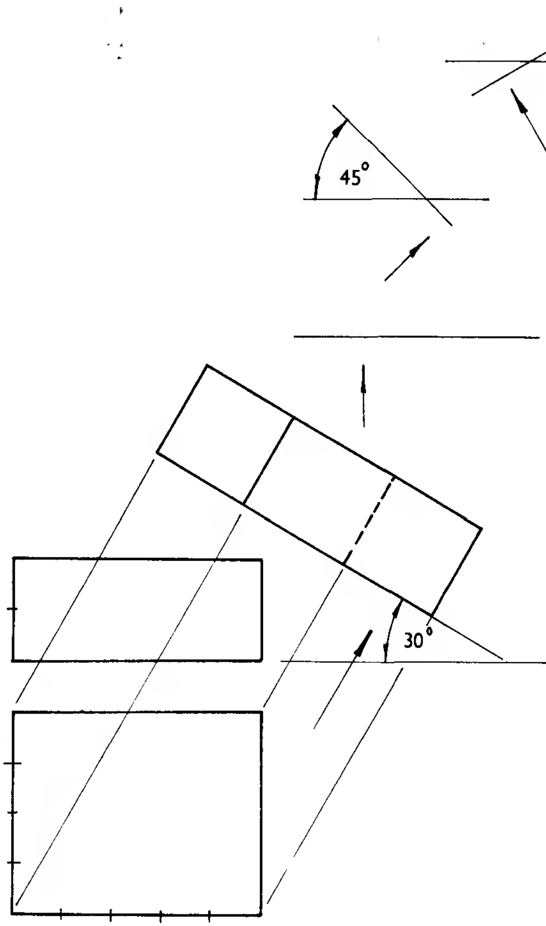


FIG 84

The grid is 10 mm and the projection first angle.

Development

Objects can be made in a variety of ways. They can be *machined* from the solid or shaped when hot, a process of *forging*. Molten metal may be poured into a cavity formed in sand, a process of *casting*. The several shapes of the component may be formed together by welding or riveting, a process called *fabrication*. If, however, the object is to be made from sheet material, the shapes forming the object are prepared on a flat sheet which is then folded or rolled to shape. This flat shape from which the object is to be cut, folded and *developed* is called a *development*.

Development may be quickly demonstrated by using a few simple everyday examples. Toilet requisites and items of confectionery are often contained in interesting packets. Cut a few small simple cardboard containers apart and establish their developments. Notice also the provision for joining the development. It will soon be evident that a cigar carton, a rectangular prism, is formed by the joining of its four sides together. Joined to the long edge of one of the sides is a top, and on the opposite edge, a bottom.

Exercise

Select an item (a toilet requisite would be most suitable) and design a container for it. It will be necessary to draw a rectangle to enclose the base of the object, a plan; and a rectangle to enclose a side elevation. From this a *development* may be drawn. Transfer the development to a piece of card. Cut it out and score the lines where it is to be folded—a ballpoint line is quite suitable for this—and fold it to shape.

More complex designs may be considered where the base is not a rectangle. Triangular, pentagonal or hexagonal bases to form prisms or pyramids are all interesting possibilities.

Draw the plan, elevation and development of a tetrahedron of 50 mm edge. Using a piece of thin card, make up the development. It may be transferred by tracing or pricking through from the development on the drawing to a piece of card placed beneath.

The development of the platonic solids is a very interesting assignment. Make one.

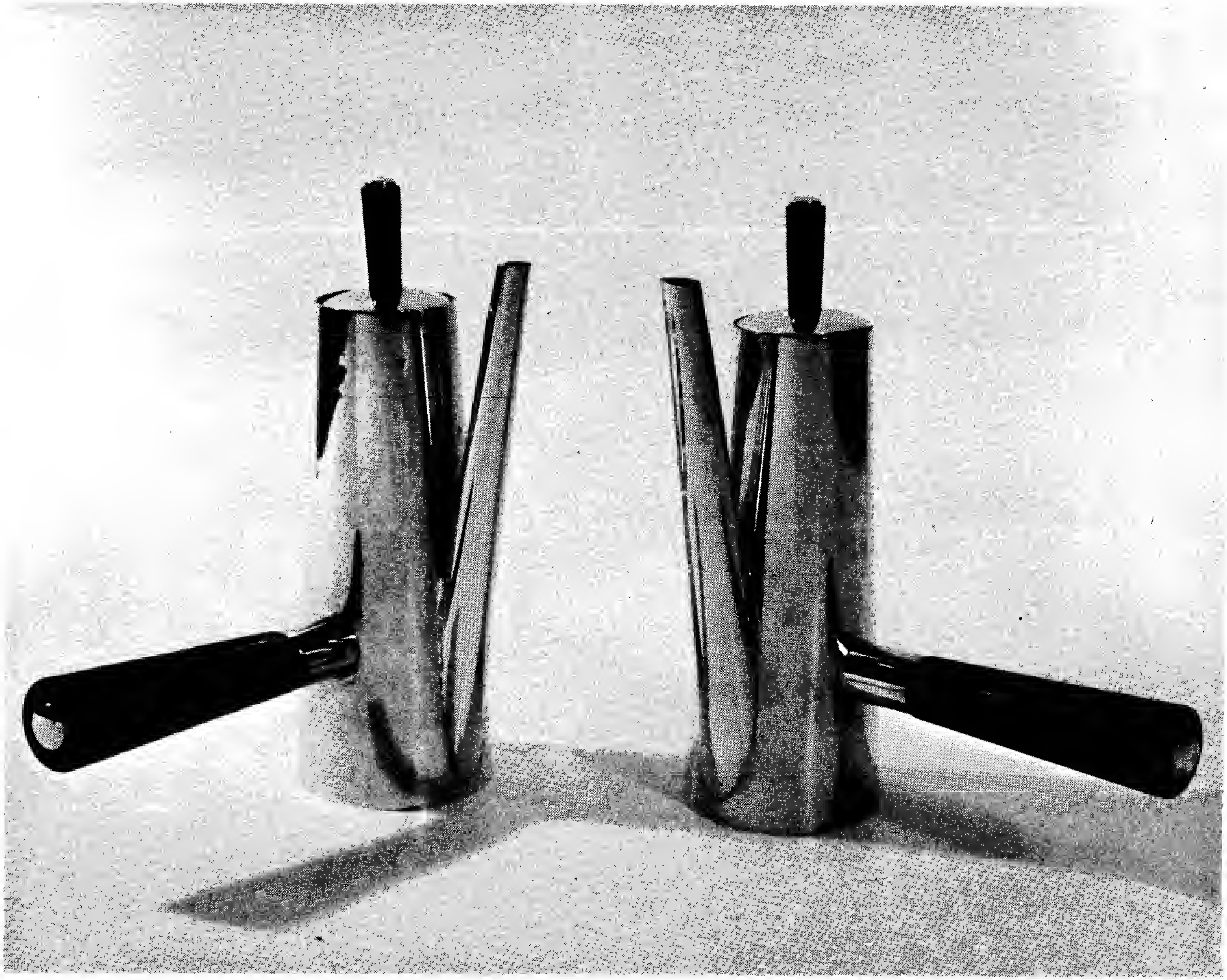
In about 60 words, describe the development of a cylinder.

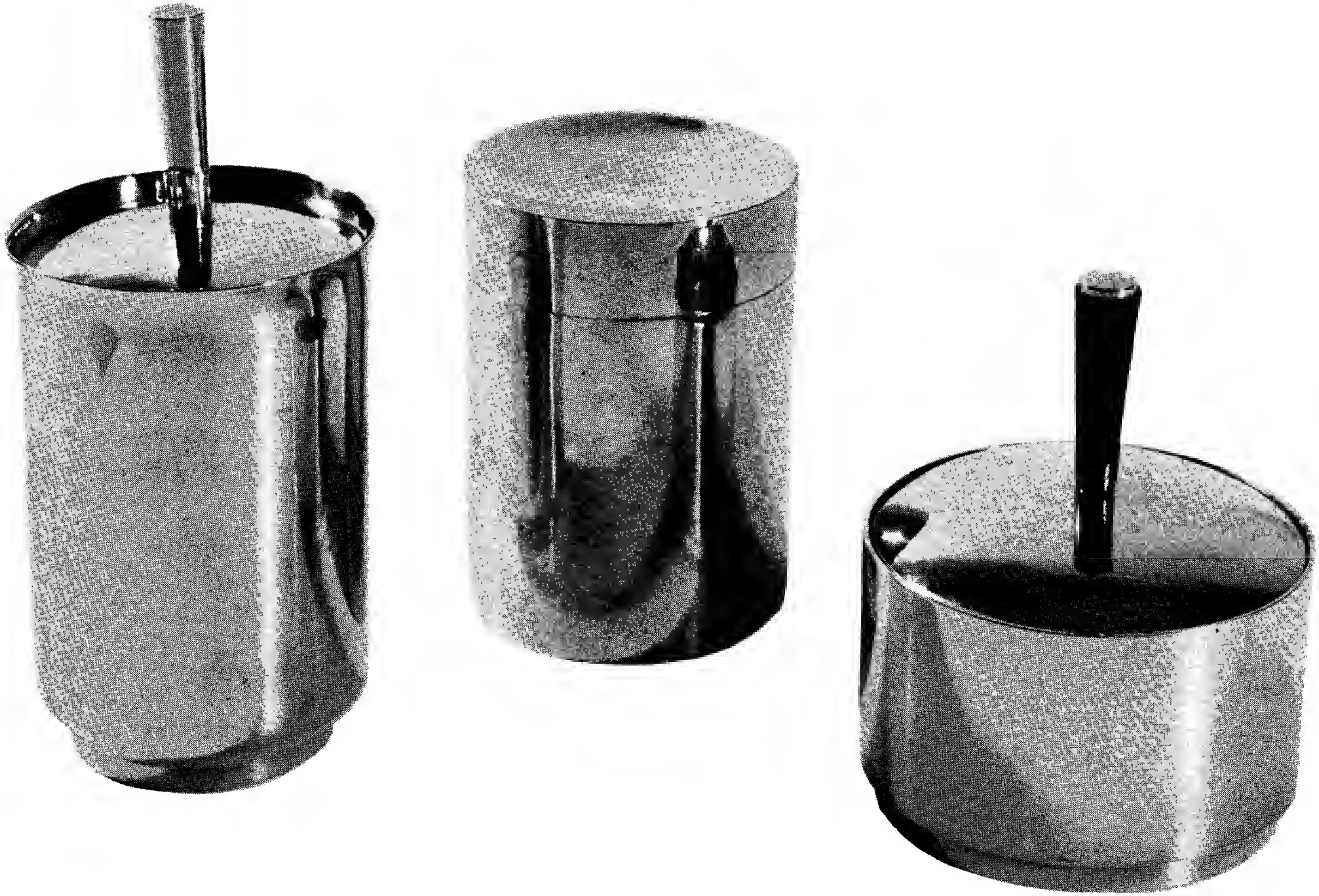
The following pages show photographs of pieces of school metalwork, designed and made by young people, using cylindrical and conical developments. The drawing of the small pot displays the method used to present drawings of this kind and shows a half section which displays not only its internal shape, but the method used in its construction. Subsequent pages show the development of a square pyramid (Fig. 86) and the curved surface of an obliquely cut cylinder (Fig. 87).

Exercise

Design either (*i*) a condiment set, or (*ii*) a tea-pot, milk jug and sugar bowl, or (*iii*) a coffee-pot and cream jug. The finished shapes are to be of developed forms and, after an initial study of each item chosen, a series of sketches will be necessary before a final selection is made. This should then be presented in orthographic style and the development of the main forms determined. The profiles of the items may be cut from white cartridge paper and presented on a sheet of sugar paper, but it is better to make three dimensional models in card or other suitable materials. This procedure is necessary if the design is to be realized.

(opposite) Coffee pots designed and made in gilding metal by a member of Vyners School, Ickenham





Various pots designed and made in gilding metal by members of Vyners School, Ickenham

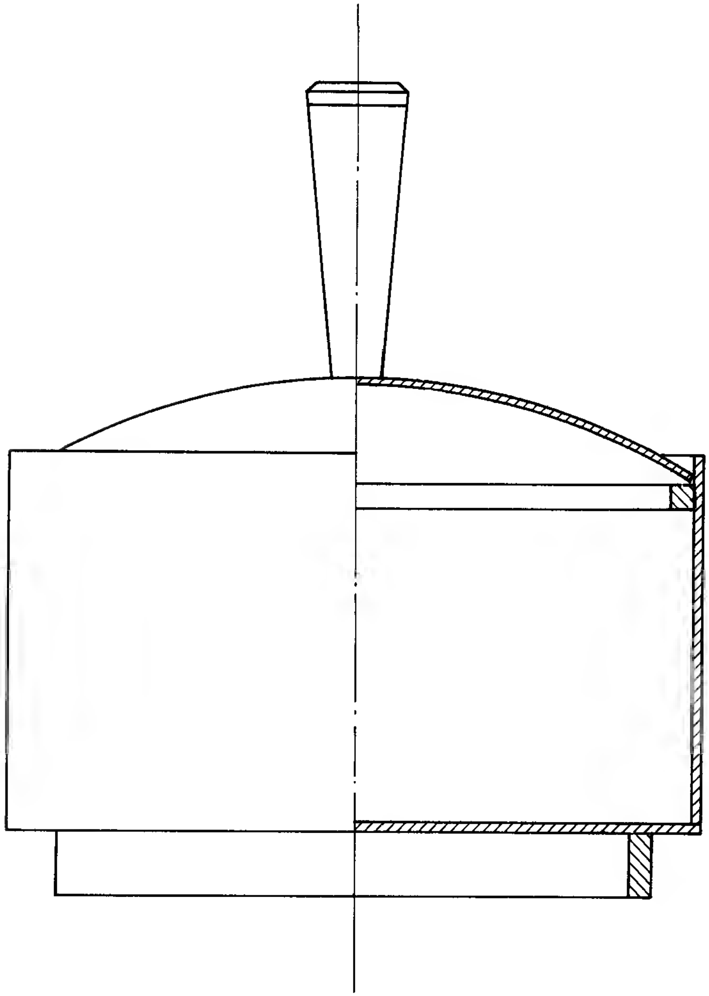


FIG 85

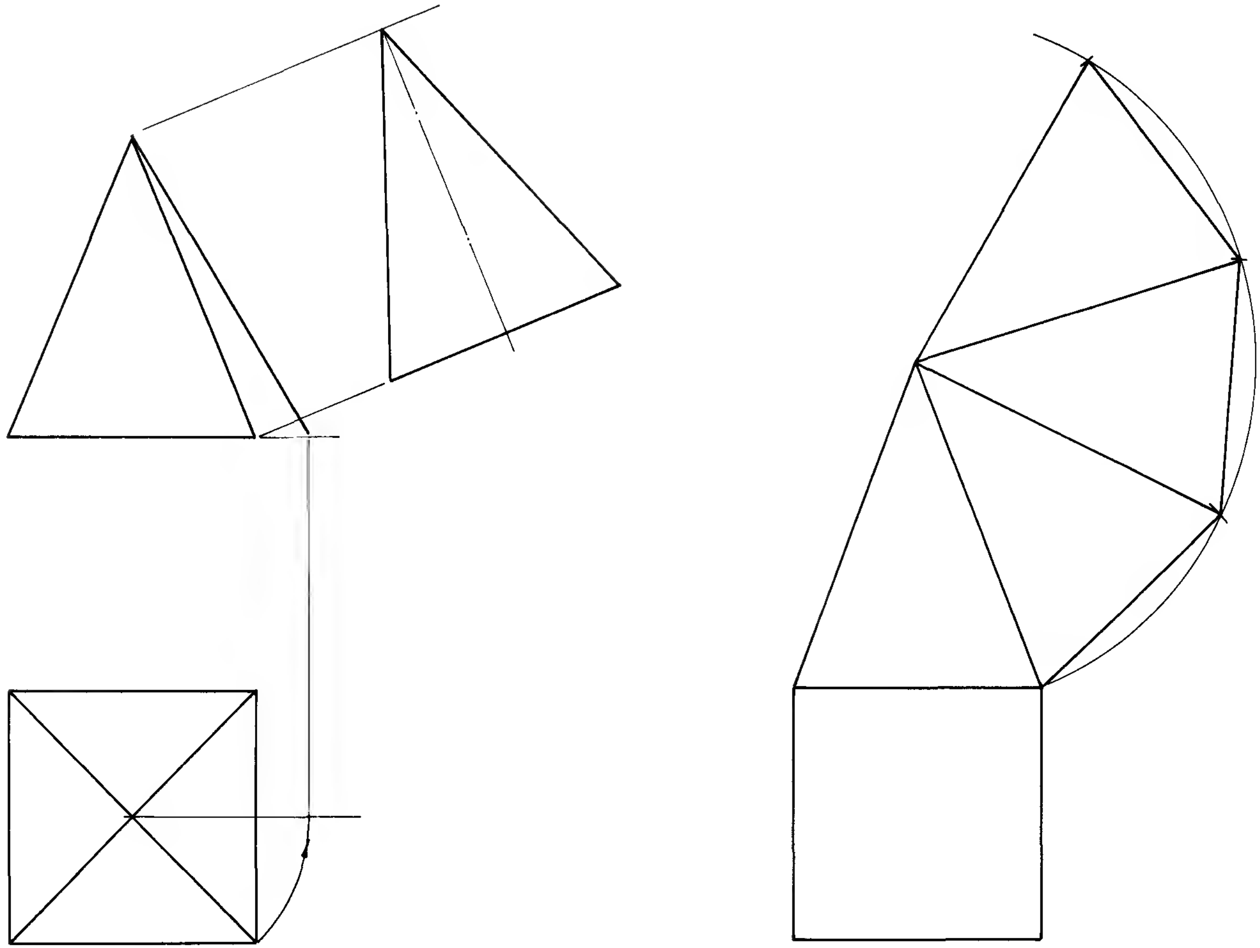


FIG 86

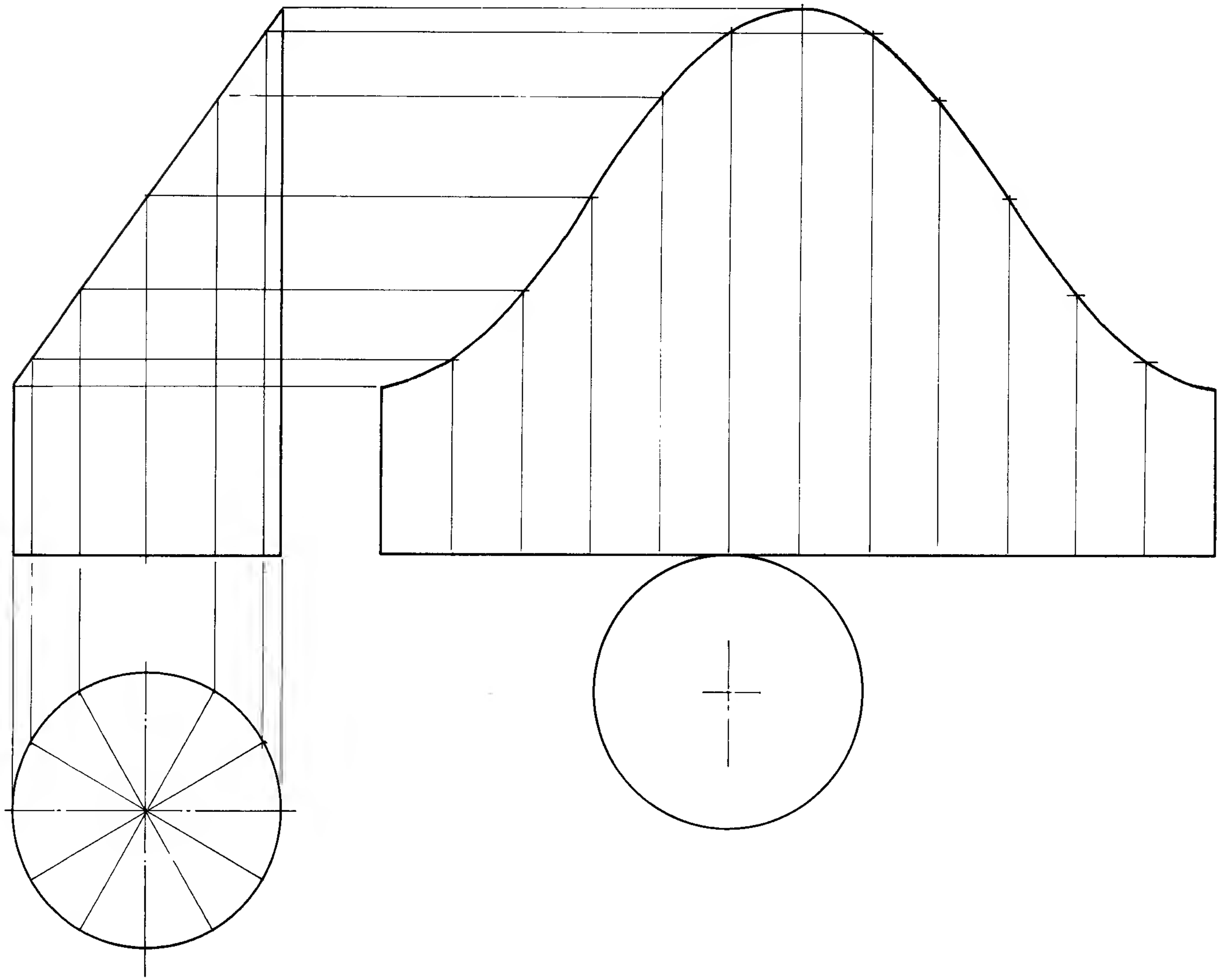


FIG 87

F

Development (continued)

Development by triangulation

This method of development considers the developed surface as made from a series of triangles. The object considered in Fig. 88 is a suitable object for triangulation. The diagonal, drawn on each face to form the necessary triangles, must, of course, be projected to give its true length. The diagonals have been considered in this example as the generators of a cone. An auxiliary projection could also have been used to give the true length of the diagonal and the true shape of the face itself.

The method of triangulation is also used for the development of *transition pieces*, connecting pieces joining one shape to another, perhaps a rectangular form to a cylinder. This is demonstrated overleaf in Fig. 90, the developed surface being considered as a series of triangles which are formed by one corner of the rectangle and one quarter of the circle. This portion of the development is in fact the development of a quarter of an oblique cone.

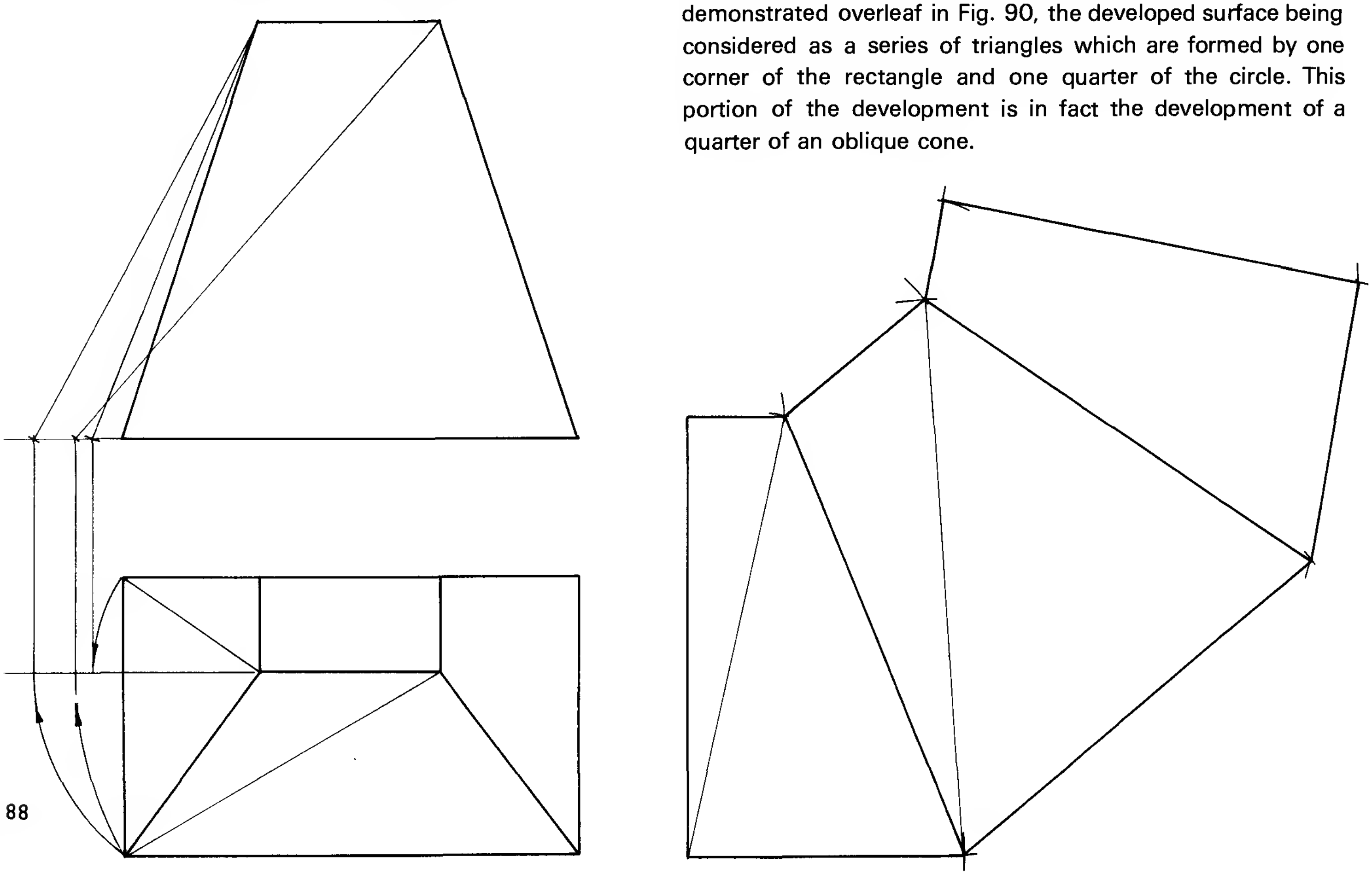


FIG 88

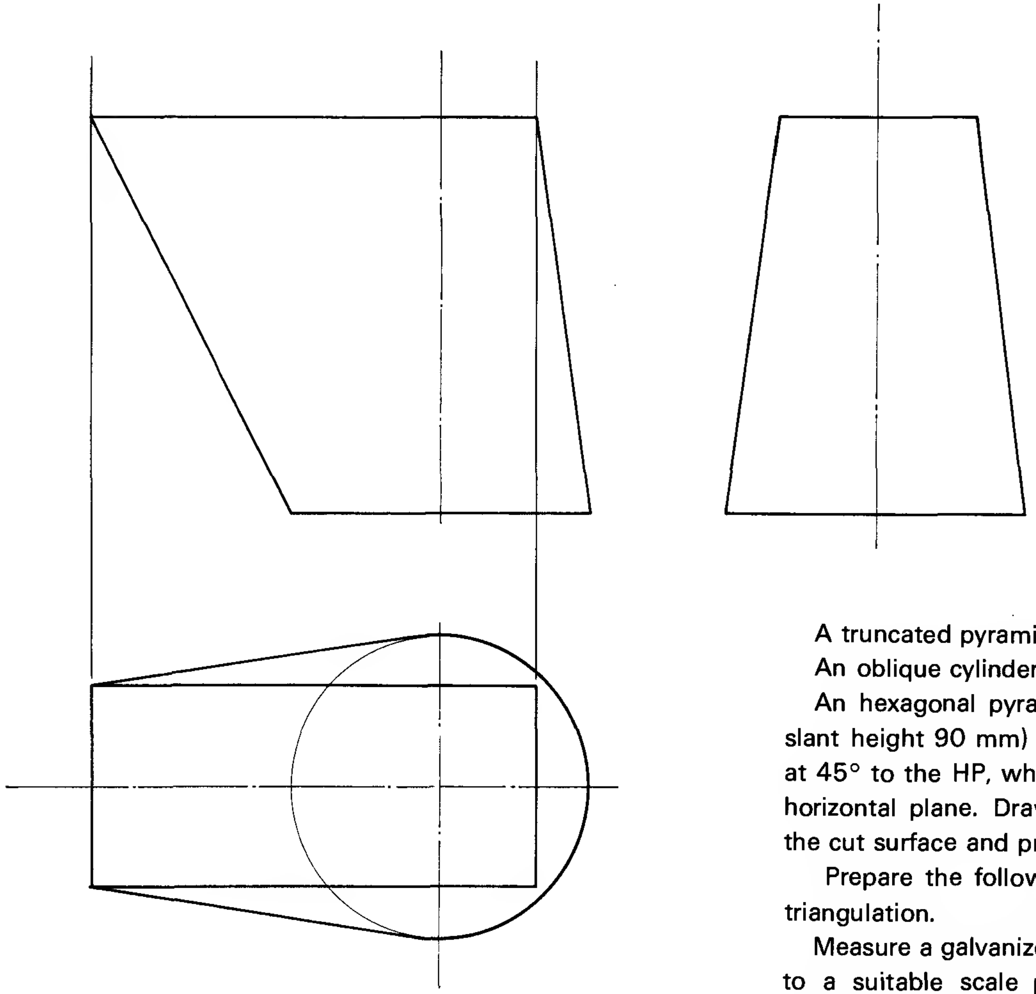


FIG 89

Exercises

Using suitable dimensions so that each complete assignment may be accommodated on an A3 size drawing sheet, prepare the following developments:

A truncated pyramid.

An oblique cylinder, axis inclined at 60°, both ends parallel.

An hexagonal pyramid, (distance across the flats 60 mm, slant height 90 mm) is truncated by a cutting plane, inclined at 45° to the HP, which enters the pyramid 20 mm above the horizontal plane. Draw the plan, elevation and true shape of the cut surface and prepare a development.

Prepare the following developments using the method of triangulation.

Measure a galvanized steel garden wheelbarrow or truck and to a suitable scale prepare a plan, elevation and auxiliary projections to show the true shape of the sides, before attempting the development. Make the shape in card. This drawing and model could also be used to determine the dihedral angle between two adjacent sides.

Prepare a development and model in card of a transition piece similar to those in Figs. 89 and 90.

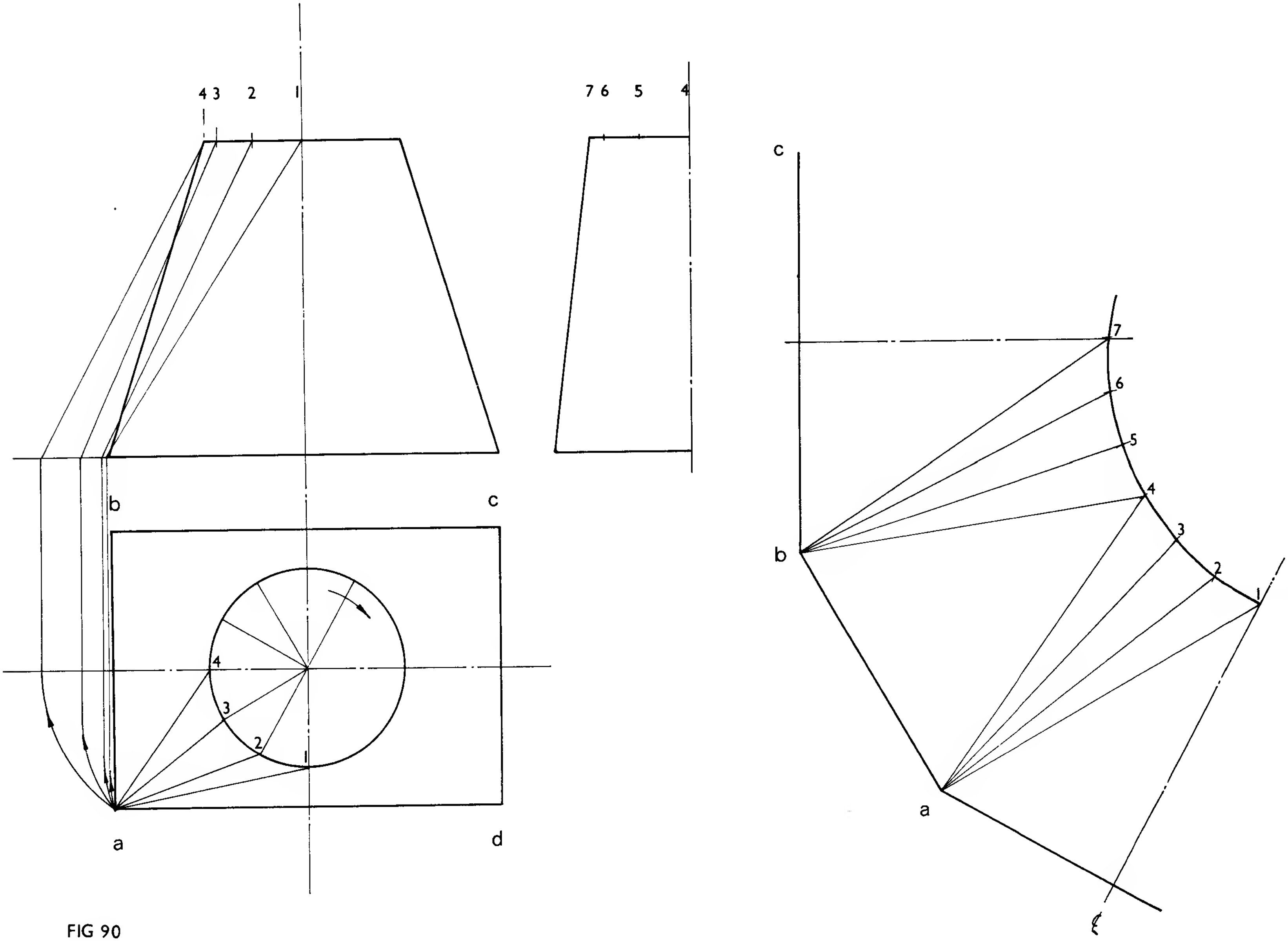


FIG 90

Interpenetration

Simple geometric solids are often used to demonstrate interpenetration and to determine the line or junction between the two solids formed when one penetrates the other.

It is a comparatively simple matter to project the salient points from one elevation or plan to another. Should additional points be required, cutting planes may be used, either *parallel with the vertical plane* or *parallel with the horizontal plane.* The intersections of these planes are projected to the adjacent view, plan or elevation. However, these cutting planes must be chosen with some care since they must reveal *simple shapes*. In a cone, a horizontal cutting plane will reveal a *circle*, a *simple shape*; but a cutting plane parallel with the vertical plane would reveal a series of complex shapes, hyperbolas. What simple shape is exposed when the cutting plane passes through the vertex?

Exercises

Using suitable dimensions so that each assignment can be contained on an A3 size drawing sheet, determine the lines of interpenetration of the solids shown in Fig. 91(A and B). Their developments may also be determined.

A scale is shown, in case difficulty is experienced in determining a suitable size.

Note of interest

If two cylinders or a cylinder and a cone, or two cones intersect each other at any angle and the curved surfaces of each envelop a common sphere, the outline of the interpenetration in the elevation will be a straight line and a normal view to this line will show an ellipse. The axes of the two solids will also pass through the centre of the sphere.

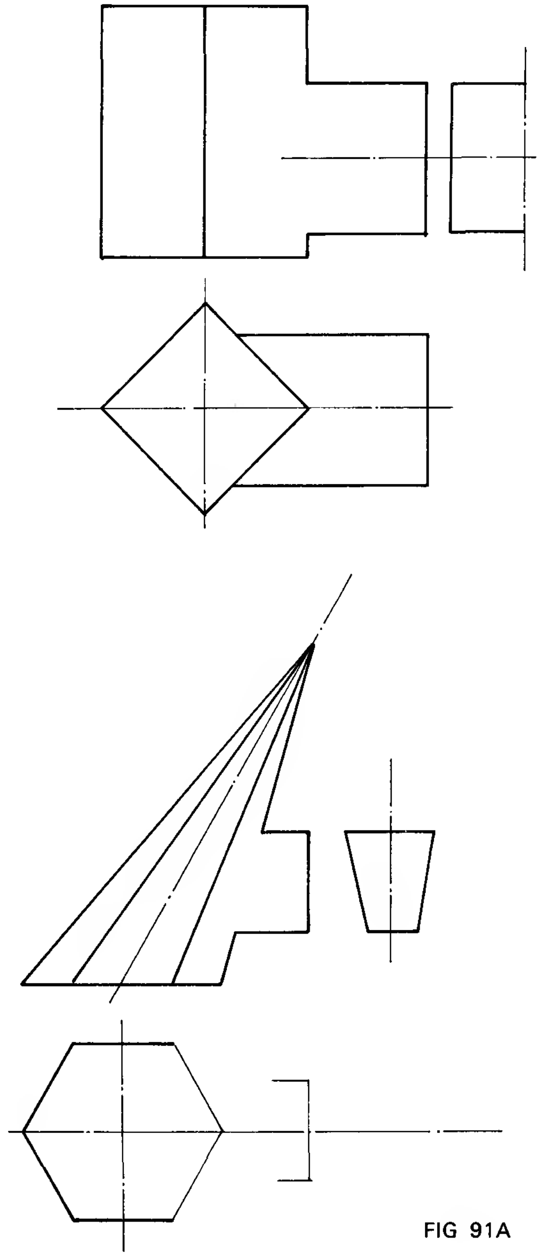


FIG 91A

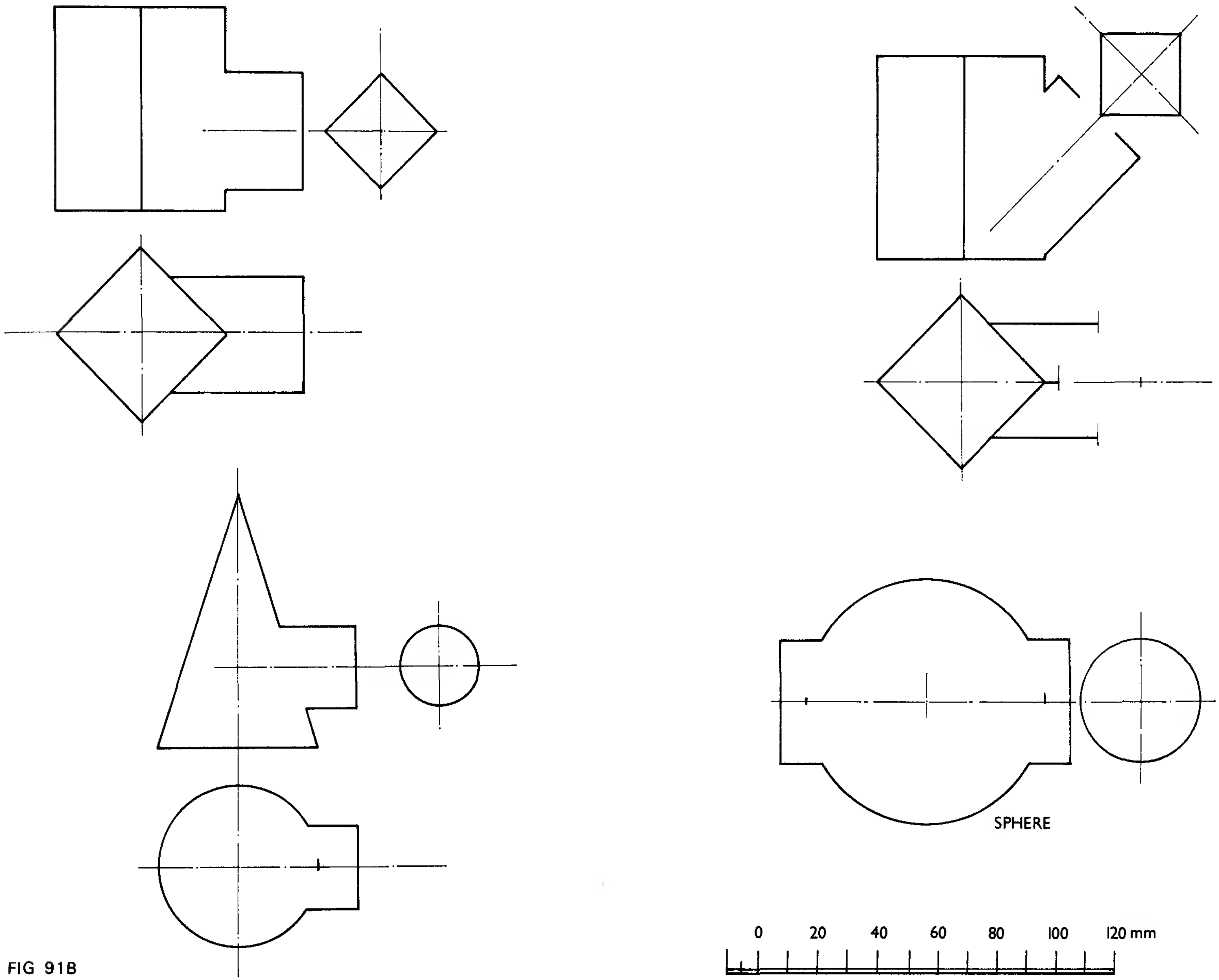


FIG 91B

SECTION THREE

Drawing and Design

Design is a topic of considerable interest and, while many aspects of it are complex, an awareness of things in everyday use can reveal many interesting details of design and a greater understanding in the use and properties of materials.

An electric light bulb is a splendid example of design. The cap of the bulb is a brass pressing. The glass bulb, to transmit the light, contains a filament made of tungsten, a metal of the highest known melting point (above 3000°C) which will glow white and give light. The conductors, the two antennae holding each end of the filament and partially enclosed in glass, must be made of a material which will possess a coefficient of linear expansion similar to that of glass. An alloy of iron and nickel possesses this quality and has replaced the use of platinum, an expensive metal. These conductors are soldered at their exit in the cap with a soft solder, an alloy of lead and tin, and the cap itself is filled with an insulating material.

Consider several everyday objects critically and write a paragraph similar to the one above about the object selected. Alternatively objects may be discussed in a group. Suitable objects could be a mortice or yale lock, a switch, a three pin plug containing a fuse, a bicycle bell, a cigarette lighter, a pen-knife, a wall can-opener and a sparking plug. Many examples come to mind and demonstrate clearly ergonomic, aesthetic and material considerations.

This section deals with drawing and design; on the left hand page or column are the specific details called for, and on the right hand page or column the parts which must be considered.

Many details have been drawn full size and dimensions may be taken directly from the drawings using dividers and a rule.

All the items chosen are familiar pieces of workshop equipment.

Detail and full assembly drawings

Suitable tracings may be prepared using detail paper, or the drawings themselves may be presented on detail paper from which dyeline prints may be taken. This will not only demonstrate a drawing office process, but will readily show the line quality of the drawing.

These dyeline prints may be used in the workshop.

Metalwork Design Topics

A small router (Fig. 92)

Prepare the following design details and present them in either first or third angle projection.

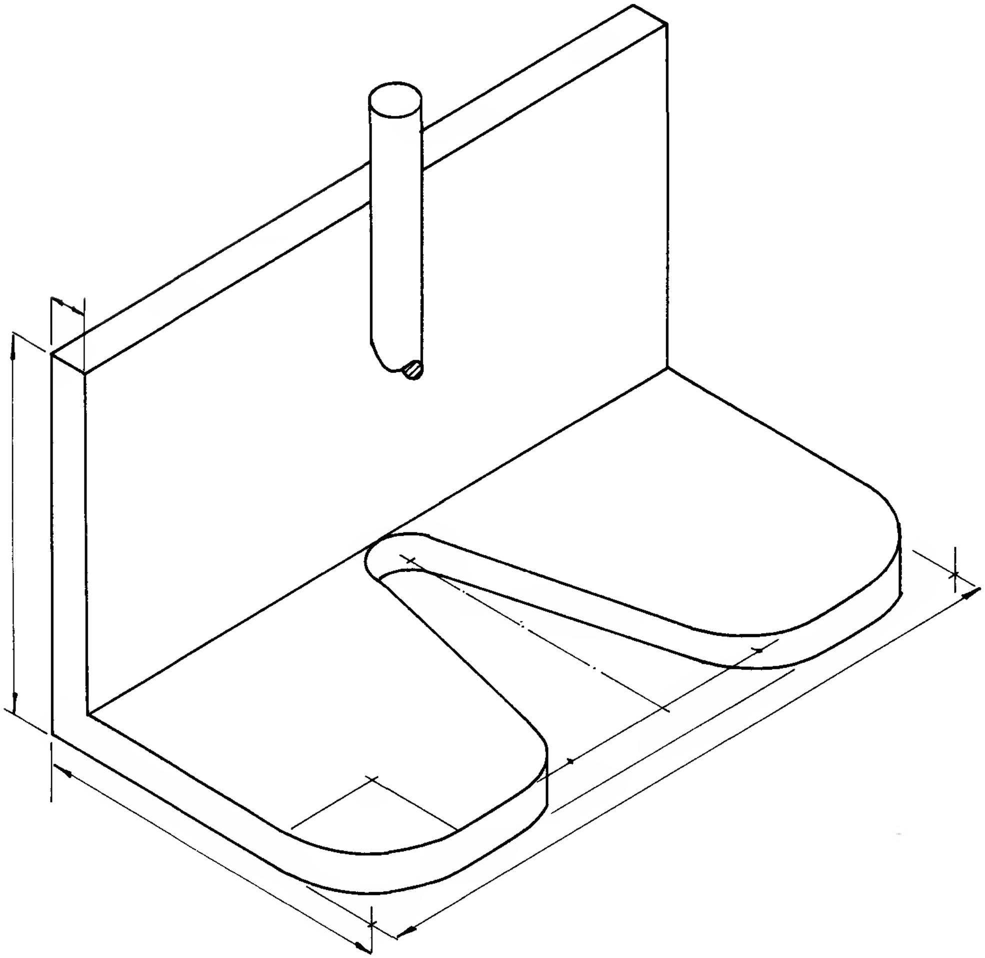
Design a suitable clamping device for the blade. Sketches of suitable designs should be developed and from these a fully dimensioned orthographic drawing should be prepared.

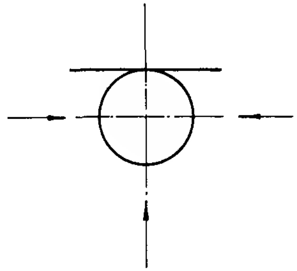
Present an orthographic drawing, three views, of the main body shown with the upright portion suitably detailed in shape and with provision for the blade, 6 mm in diameter to be secured. A sectional elevation may be introduced at this stage.

The drawings should be suitably dimensioned and the materials specified.

The major problem here is the clamping of the blade and a diagrammatic representation of this is shown alongside the isometric drawing. The blade must be restrained in three directions, indicated by the arrows. It will be necessary to draw this component, and others similar in subsequent design assignments, to an enlarged scale. Twice full size would be a suitable scale for this detail.

At a later stage this assignment could include a full assembly drawing, an isometric or an exploded isometric drawing.





DESIGN PROBLEM

FIG 92

DIMENSIONS IN MILLIMETRES FULL SIZE

Metalwork Design Topics

Another small router (Fig. 93)

Given the overall shape of the pattern from which a small router is to be made, complete the views presented and add one elevation.

Design a suitable clamping device for the blade. Sketches of suitable designs should be developed and from these a fully dimensioned orthographic drawing should be prepared.

Present a complete full size assembly drawing which should incude a section through the axis of the blade (without dimensions).

The drawings should be suitably dimensioned and the materials specified.

This design could also include, at a later stage, isometric drawing.

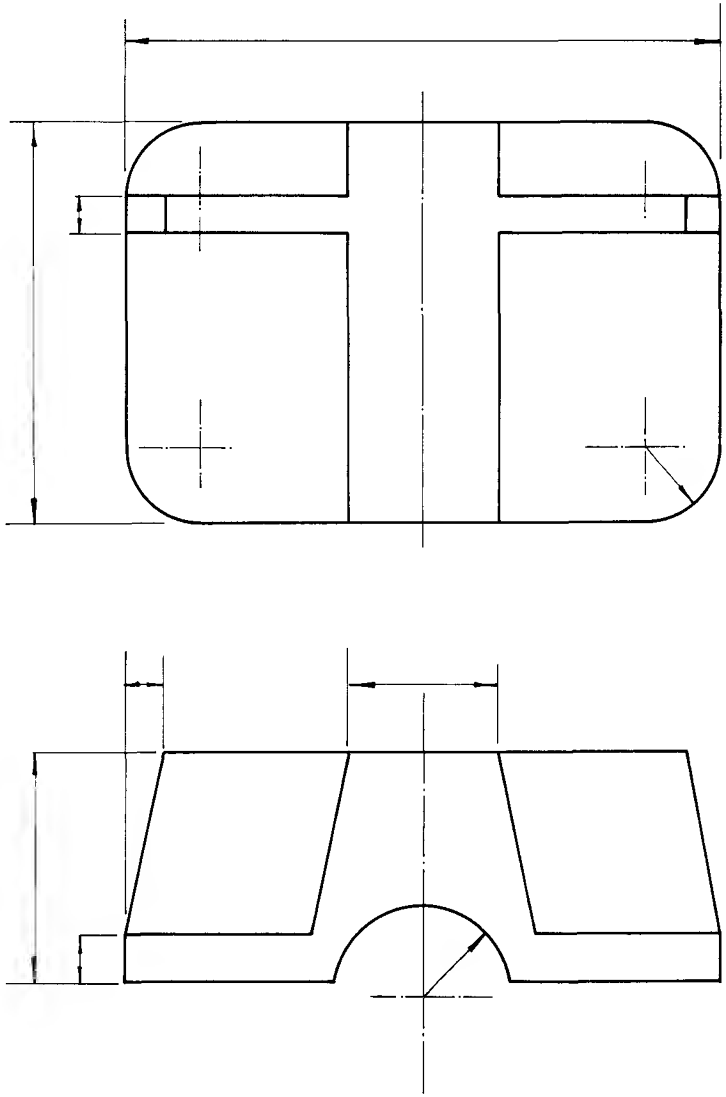


FIG 93 FULL SIZE THIRD ANGLE

Metalwork Design Topics

A small plane (Fig. 94)

Prepare the following design details; present them in either first or third angle projection.

Using the drawings prepared:

1. Design a suitable clamping device to secure the blade of the plane in position. This should be complete in every detail, the blade, the clamp and the method whereby the angle of the blade is determined, together with any other necessary details. The detail drawings should be suitably dimensioned and the materials specified.
2. Make a complete assembly drawing, full size and without dimensions.
3. Draw an auxiliary plan, normal to the blade. A sectioned elevation may also be called for.
4. Make an isometric drawing of the whole, or a part.

This straightforward elevation of the side of the plane may be used for the intersection of arcs and also the transverse common tangent. By using accurately prepared templates, or drawings, say twice full size, the centres of the arcs of the circles may also be determined.

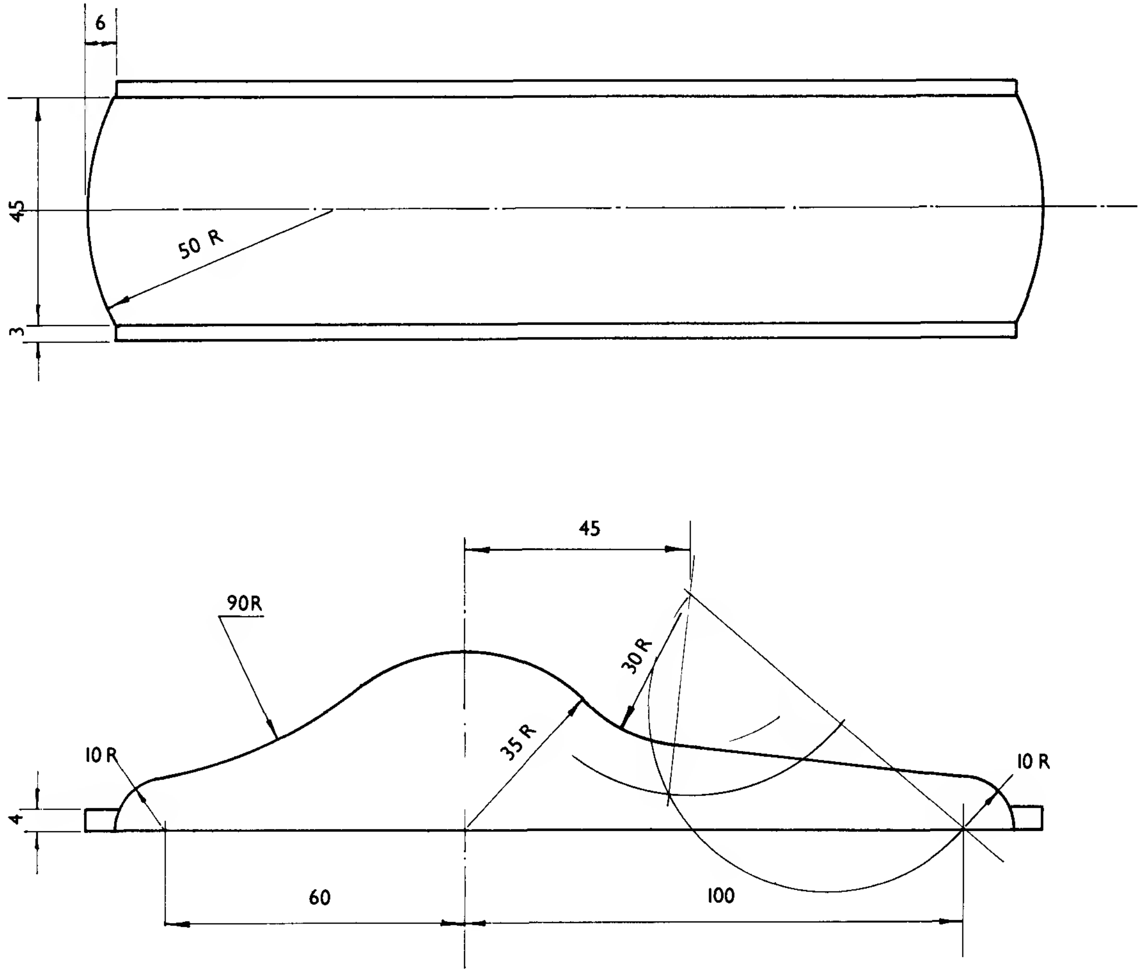


FIG 94 DIMENSIONS IN MILLIMETRES THIRD ANGLE

Metalwork Design Topics

Vice (Figs. 95 and 96)

Prepare the following design details and present them in either first or third angle projection.

The drawing shows the basic details of two small vices, one for metalwork and one for woodwork.

Prepare suitable designs for either one or both of these vices. It will be necessary to design a suitable screw and nut, a method for retaining the moveable jaw on the screw, a means to prevent the moveable jaw turning, and a method of fixing the vice to the bench. This could be a permanent or temporary fixture.

When suitable design sketches have been developed, prepare:

1. Detail drawings which should be suitably dimensioned and the materials specified.
2. A complete assembly drawing, full size and without dimensions.
3. An isometric drawing. (Use an ellipse template and omit the details of the screw thread.)

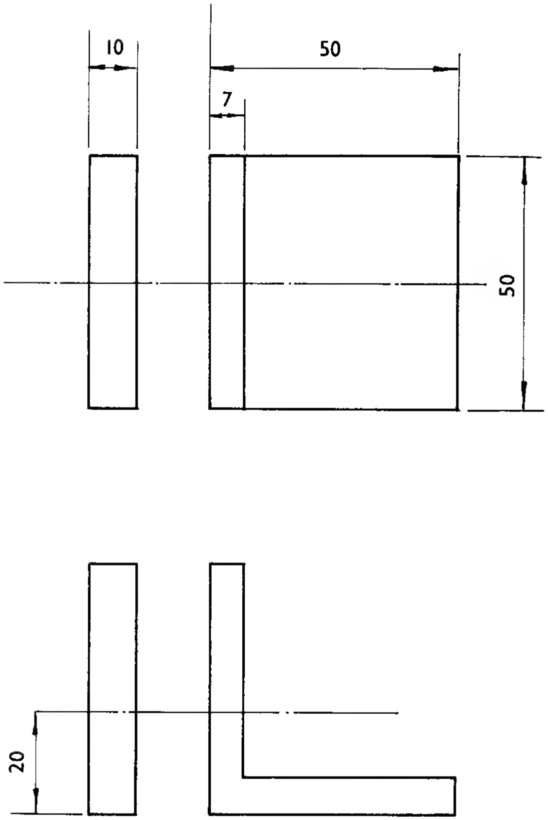


FIG 95

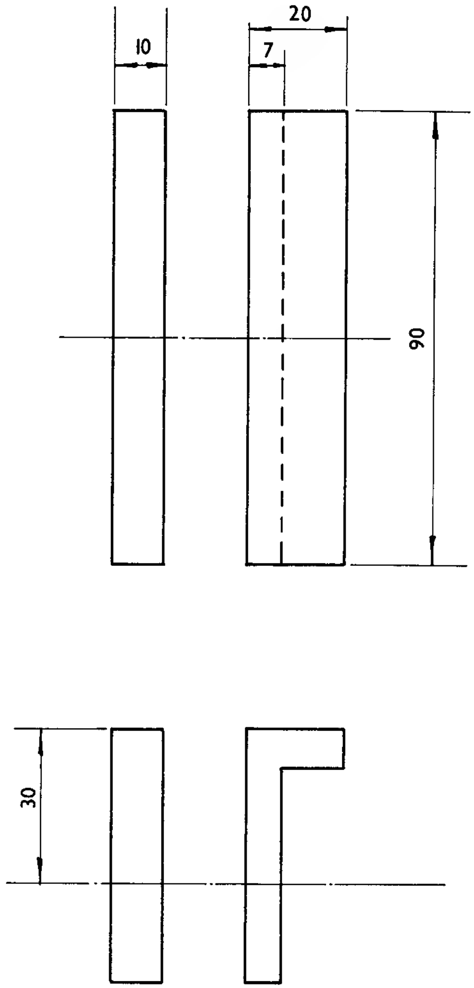


FIG 96

Metalwork Design Topics

Tool post (Fig. 97)

Prepare the following design details and present them in either first or third angle projection.

The drawing shows the compound or top slide and the centre height of a centre lathe, all the necessary details required for the design of a four-way tool post.

Using the details given, design a four-way tool post to take tool bits 10 mm square.

Provision should be made for the tool post to be clamped in any position and provision could also be included for it to be indexed at 90 degree intervals.

When suitable design sketches have been developed, prepare:

1. Detail drawings which should be suitably dimensioned and the materials specified.
2. A complete assembly drawing, to include a sectioned elevation, full size and without dimensions.

On a separate sheet of paper write a paragraph to explain why the tool post that you have designed is to be preferred to the American type tool post.

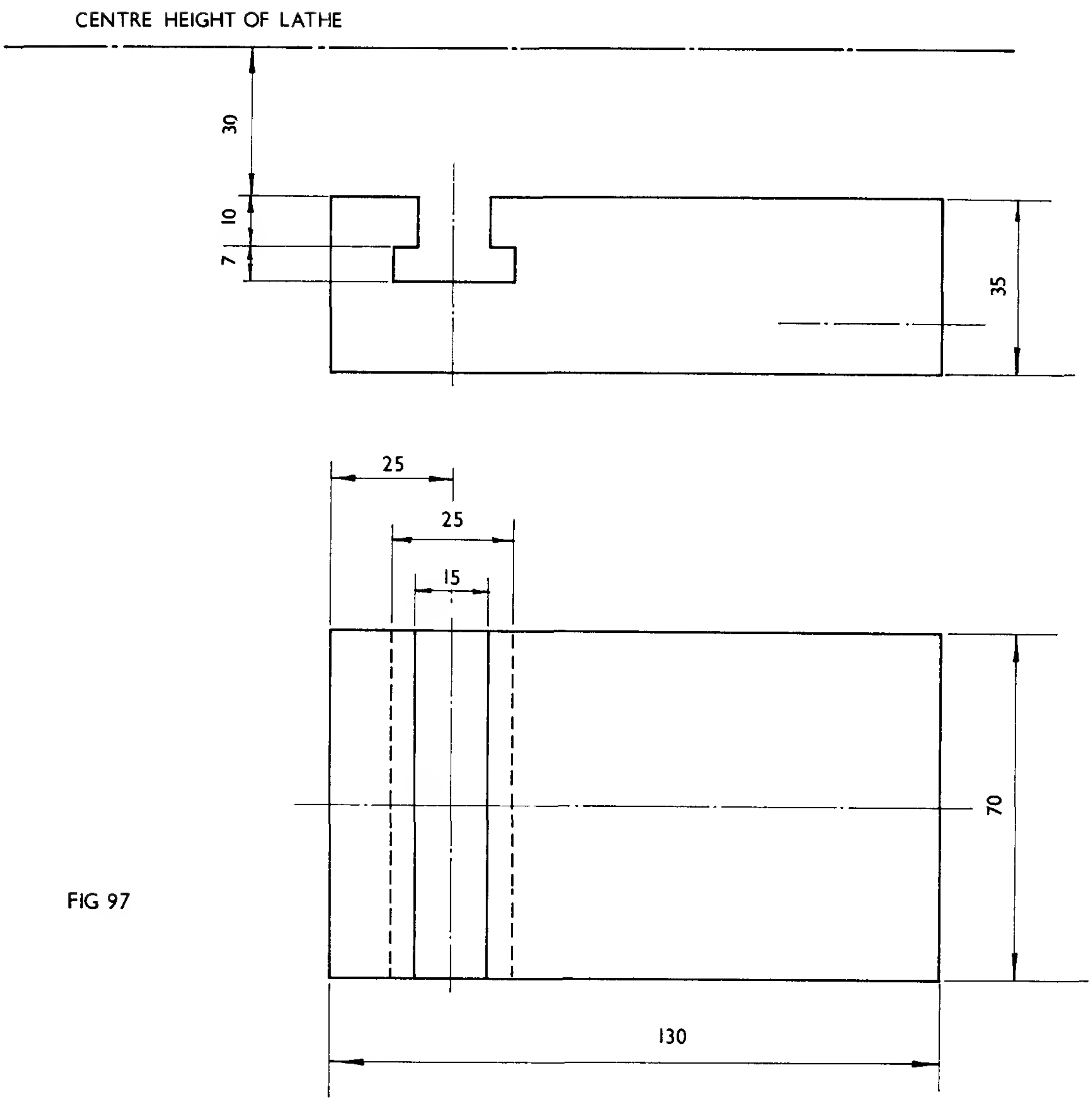


FIG 97

DIMENSIONS IN MILLIMETRES

Metalwork Design Topics

Router (Fig. 98)

Prepare the following design details and present them in either first or third angle projection.

The drawing shows the main component of a router.

Prepare suitable designs for the handles, together with a method of fixing them to the main casting, a device for clamping the blade and a means whereby the blade may be raised and lowered.

When suitable design sketches have been developed, prepare:

1. Detail drawings which should be suitably dimensioned and the materials specified.
2. A complete assembly drawing to include a sectioned elevation, full size and without dimensions.

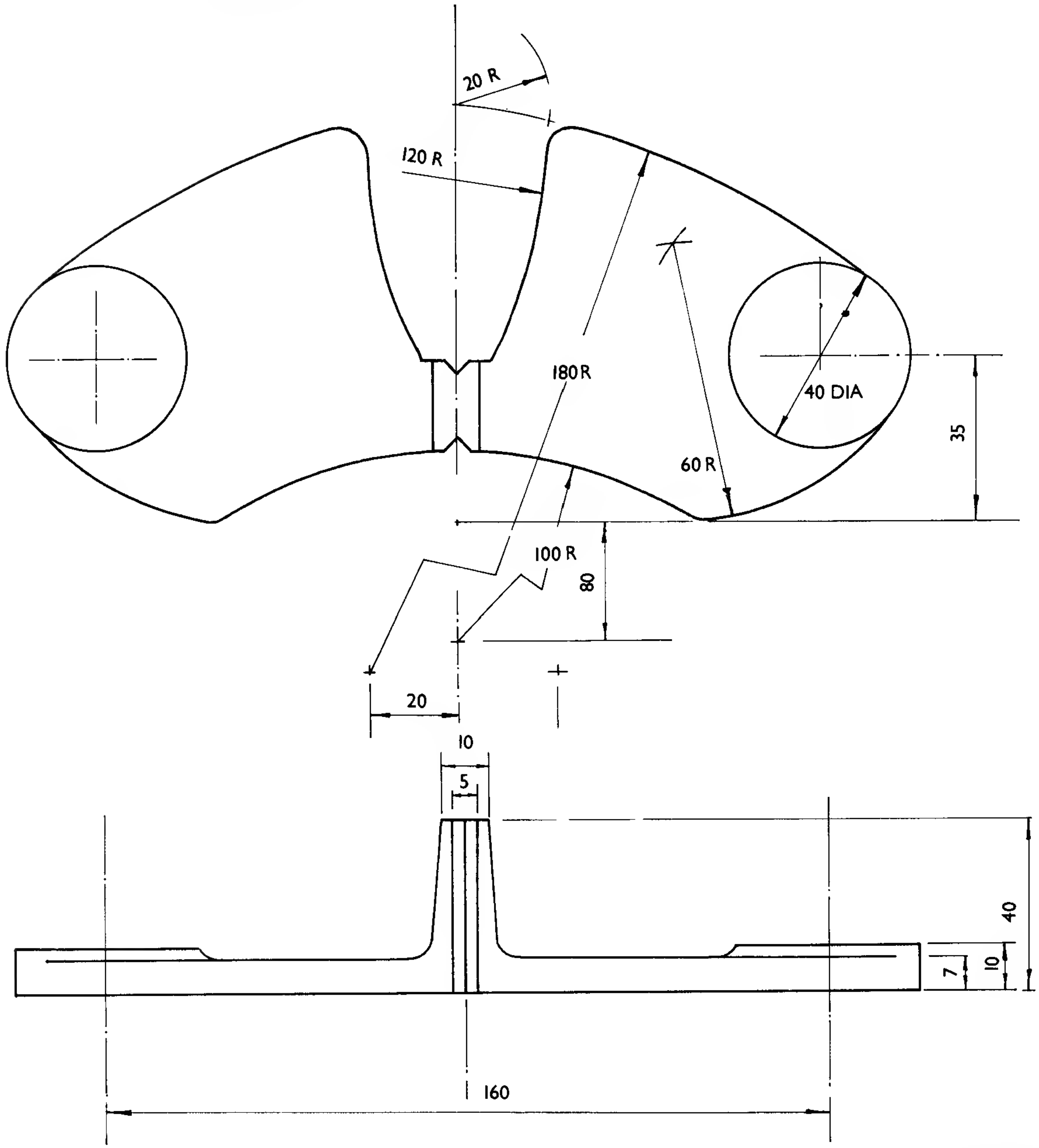


FIG 98

DIMENSIONS IN MILLIMETRES

Drawings for woodwork

Woodwork drawing should, if possible, be drawn full size. If this is not possible, the drawings may be drawn to scale. The scales most commonly used in metric measurement are multipliers and divisors of 2, 5 and 10. $\frac{1}{8}$ scale is usually employed if imperial measurements are used.

Small pieces of work are often drawn full size.

Pieces of work which cannot be drawn to full size are usually drawn to scale, and it will often not be possible to show small details: a full size drawing will be necessary to show these details together with the construction. The scale drawing will normally show the overall dimensions while the full size layout will be fully dimensioned.

The drawings may be presented on detail paper from which dyeline prints may be taken. These prints can be used in the workshop. Additional information and modifications may be added to them as is necessary.

Mr. J. Maynard's book, *Constructions and Workshop Practice in Woodwork*, also published by Hulton, will be found to be most useful in dealing with design topics in this section.

Woodwork Design Topics

A wall cabinet to contain twenty small boxes 100 × 60 × 25 mm for storing small items

Design a small cabinet for a workshop to satisfy the above requirements. It may be either free standing or fixed to the wall. The small boxes which it is to contain are made of metal and are already available.

When suitable design sketches have been developed, prepare:

1. The development and the making in card of one of the small boxes.
2. A *full size* drawing in third angle projection showing the overall dimensions only and one metal box in position.
3. A *full size* working drawing of one side of the cabinet, fully dimensioned and showing the construction details necessary.

Specify the materials, prepare a cutting list and indicate the type of finish which would be suitable.

A useful box for a particular purpose

Design a box for a particular purpose:
a box to contain drawing instruments
a box for a pistol drill
a tool box
a needlework box
a shoe cleaning box
or a box without a lid to fit into an existing kitchen drawer to contain cutlery ...... are just a few such items.

After suitable design sketches have been developed, prepare:

1. A *full size* working drawing in third angle projection, showing the overall dimensions only.
2. *Full size* detail drawings, fully dimensioned, showing the construction details.

Specify the materials, prepare a cutting list, and indicate the type of finish which would be suitable.

Woodwork Design Topics

Clock case

Design a small clock case to be made from wood, and to accommodate a clockwork movement of 60 mm diameter and 30 mm deep. The three fixing holes, 4 mm diameter, are equally spaced on a pitch circle diameter of 45 mm. The movement is wound from the back and the spindle of which the hands are to be fixed protrudes 10 mm from the plastic case of the movement.

After satisfactory design sketches have been developed, prepare:

1. *Either* a *full size* isometric drawing, if the shape of the case is to be straightforward (e.g. rectangular), *Or* three orthographic views together with any sectioned elevations if necessary, full size and without dimensions.
2. A *full size*, fully dimensioned working drawing to show details of construction, if this is necessary.
3. A *full size* drawing to show the constructions and layout necessary for the face of the clock.

If the shape is simple or straightforward, a cardboard or balsa wood model may be made. When presented in three dimensions in this way its form or shape can be more readily appreciated.

4. A design of the hands may also be prepared. The diameter of the spindle to carry the hour hand is 6 mm and the minute hand spindle is 2 mm diameter.

Bathroom cabinet

Prepare the following design details and present them in either first or third angle projection.

The cabinet should have sliding doors and its overall dimensions should not exceed 400 × 300 × 100 mm. The design should show how this cabinet is to be fixed to the wall and the positions of the shelves or compartments. It will be necessary to measure toilet items normally found in these cabinets.

When suitable design sketches have been developed, prepare:

1. Three views of the cabinet, *half full size* and without the sliding doors.
2. A *full size* drawing, fully dimensioned, of one end to show the position of the shelves, the corner joint and the position of the sliding doors.

Specify the materials, prepare a cutting list and indicate the type of finish.

Woodwork Design Topics

Medicine cabinet

Everyday accidents occur within the home and are far greater in number than those of the much publicised road accidents.

A medicine cabinet may contain harmful things and it is desirable that a cabinet of this kind should be, if not beyond the grasp of a child, impossible to be opened by him.

Design a small medicine cabinet, whose dimensions should not exceed 200 × 250 × 60 mm. The door is to be hinged and fitted with a catch which is beyond the comprehension or the manual dexterity of a small child to unfasten. The catch may be made from plywood or sheet brass or any other suitable material.

When suitable sketches have been developed, prepare:

1. An isometric drawing of the cabinet, *half full size*.
2. A *full size* drawing, fully dimensioned, of one side of the cabinet to show the position of the shelves, hinges and the necessary joint details of the corner.
3. Development sketches and a working drawing of a safety catch for the door. Its position may be indicated on the isometric drawing.

Specify the materials, prepare a cutting list and indicate the type of finish.

Poisoning kills five hundred young people each year. The big dangers are ordinary household substances which are poisonous, and the contents of medicine cupboards. The first group includes items from polishes to disinfectants, paints to weedkillers and perfumes: there are an estimated 25,000 potentially poisonous substances on the market, and 1000 more a year are being produced. In the second group aspirin is the most likely danger. These dangers may be prevented by fixing the medicine cupboard out of reach of children, and keeping it locked.

Woodwork Design Topics

Book rack

Design a book rack which is to be free standing on a table or desk to hold a few books which are in current use. It may be either of fixed length or extending and if of the latter type it should not exceed 450 mm when fully extended and not less than 300 mm when closed.

It will be necessary to measure a few average size books to determine the size and shape of the ends.

When suitable design sketches have been developed, prepare:

1. A *full size* working drawing, in first angle projection, showing the overall dimensions only.
2. *Full size* detail drawings fully dimensioned, showing the construction details.

Specify the materials, prepare a cutting list and indicate the type of finish which would be suitable.

A small coffee table

Design a small coffee table, to be made from wood; the dimensions of the top are not to exceed 450 mm × 800 mm.

When suitable design sketches have been developed, prepare:

1. A *scale* drawing of the table, three views in third angle projection showing the overall dimensions only.
2. A *full size* drawing, third angle, of one leg fully dimensioned to show the construction details necessary, also the section and end details of the rails.
3. Prepare a sectioned drawing, *twice full size*, and on the same sheet as the full size drawing of the leg, to show how the top is to be fixed to the under frame of the table.

Specify the materials, prepare a cutting list and indicate the type of finish which would be suitable.

Woodwork Design Topics

Hall fitment for wall mounting, containing a drawer

Design a hall fitment which is to be fitted onto the wall and should not exceed 750 mm in length and should be of sufficient width to accommodate a telephone. This fitment is also to contain a drawer.

When suitable design sketches have been developed, prepare:

1. A working drawing, *half full size*, in third angle projection, showing the overall dimensions only.
2. *Full size* detail drawings, fully dimensioned, showing the construction details.
3. A detailed drawing of the drawer, showing the construction details, *full size*.
4. Sketches of a suitable drawer handle, to be made from either metal or wood.
5. Sketches, on the same sheet as the handle, to show how the fitment is to be fitted to the wall.

Specify the materials, prepare a cutting list and indicate the type of finish which would be suitable.

A child's wooden toy

Prepare, in first or third angle projection, the design for a toy, in wood. It should be robust and present a pleasant tactile quality, a quality which makes it pleasant to touch.

Toys are for enjoyment and fun and they are also very important to a child's development. There are many factors to be considered when designing a child's toy. The age of the child will determine the type of play the child requires and the toy should satisfy these needs. Toys which present the child with problems of selection and the development of manipulative skills are valuable to a very young child. If paint is to be used it should be non-toxic, and there should be no pieces which could be easily detached and swallowed or be hamful to the child.

Examine some well designed toys; look at them critically.

1. Present the finished design full size or to scale.
2. On a separate sheet show all the details necessary for its construction, joints etc., fully dimensioned.
3. All the relevant sketches of ideas leading to the finished design could be suitably displayed on another sheet.

APPENDIX

Drawing Equipment

Pencils

The most important piece of equipment is a pencil and these should be of the best possible quality. Pencils vary in hardness, the hardest pencil being 10H and the softest 8B, but these extremes of hardness are infrequently encountered or used. It is possible to use clutch pencils which are devices for holding a pencil lead, usually two millimetres in diameter, and these can be obtained in all grades. Leads of a rectangular form may also be obtained. A few coloured pencils are useful in technical drawing so that various items may be more clearly shown. The Eagle Verithin, Staedtler Mars Lumochrom, and Faber-Castell Goldfaber are suitable good quality colour pencils.

For sharpening the pencils a pocket pencil sharpener or lead pointer for clutch pencil leads is the most straightforward method. Compass leads may be sharpened by using either very fine glass paper or flour paper. Flour paper may also be used for the final sharpening of all pencil leads.

There are special pencils for use on drafting films and papers. The leads of these pencils resist the abrasive qualities of the paper and are sufficiently dense to withhold the light during printing.

Paper

The factors governing the purchase of paper are weight, size and quality. All sizes of drawing paper sheets are derived from the AO size, its area being one square metre and the ratio of its sides 1 to $\sqrt{2}$. All other sizes are sub-multiples of this basic size and the sides of the sheets will always be in the same ratio. The next smaller size, A1, is half the area of the AO size. The dimension which has been halved is the longest side and for an A2 sheet the longest side of the A1 sheet is halved. The A2 size sheet is 594 $\times$ 420 mm and this is similar in size to the half imperial sheet and the A3 size is similar to that of the quarter imperial sheet.

The weight of the paper is another factor to be considered and the unit of measurement in this instance is grammes per square metre. A normal weight is 120 grammes for cartridge paper, and for detail and tracing papers 60/65 grammes.

Drawing board and instruments

The most convenient size for the majority of drawing work will be an A2 size drawing board, together with a suitable tee-square. The tee-square may be made of beech. It may have a plastic blade or it may be mahogany with an ebony edge. It may be possible to have an A2 size drawing board with a parallel motion in place of a tee-square.

There is a large variety of drawing instruments to choose from. A half set consists usually of a pair of compasses, pencil/divider with a lengthening bar and a pencil spring bow. A giant bow with interchangeable pen and pencil attachments may be preferred to a half set; these are extremely useful and accurate for both spring bow and compass work although a smaller spring bow will be found to be most useful for small circles as it can be more easily controlled.

A collection of drawing instruments may be built up gradually. When an instrument case is necessary, it may be designed and made by the student. Alternatively, the instruments may be kept in a chamois leather roll.

A pair of set-squares will be necessary (a 60/30° and a 45°). The longest cathetus (longest perpendicular) for the sixty degree set-square should be about two hundred and fifty millimetres, the thickness of the set-square two millimetres.

Drawing Layout

It is often desirable to have a standard arrangement for a drawing sheet and it will be necessary to consider the various requirements of the departments concerned. Many large drawing offices use sheets of standard size and layout on which the basic format is already printed.

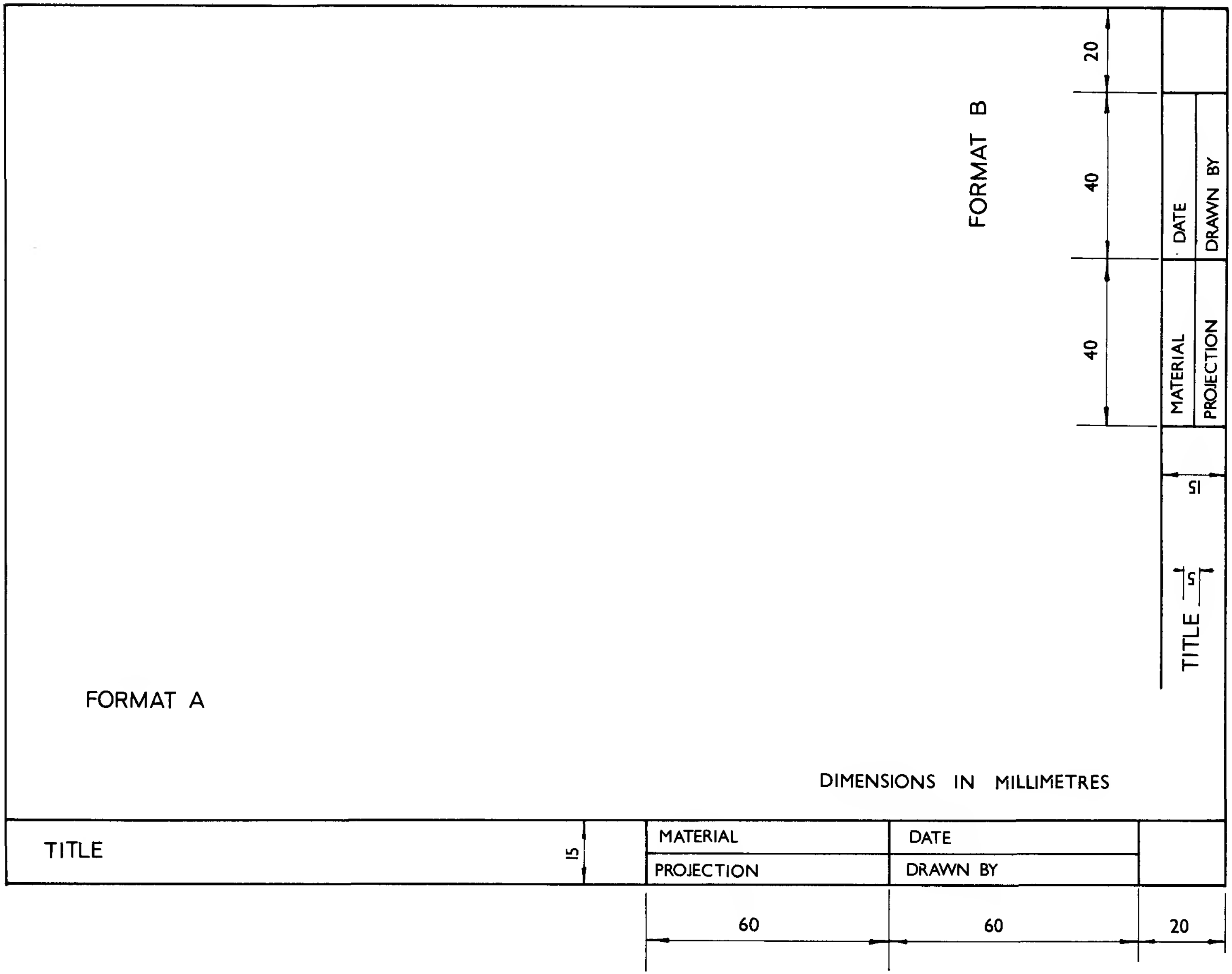
In general the sheet should always provide the following information:

The title or description of the drawing
date, and name of draughtsman
material
the system of projection and the unit of measurement.

Two examples incorporating the above items are shown on the adjacent page, format *A* will be suitable for the majority of drawings where the long edge of the drawing sheet is horizontal, and format *B* is suitable when the long edge of the drawing sheet is vertical.

Alternatively, it may be considered desirable to have a block or rubber stamp produced containing the necessary details, similar to those mentioned, and to be applied in the bottom right-hand corner, it would only then remain for the student to insert the necessary information and draw in the border.

The use of both sides of the drawing sheet is inconsistent with good drawing office practice.


FORMAT B
20
40
40
DATE
DRAWN BY
MATERIAL
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15
5
TITLE
FORMAT A
DIMENSIONS IN MILLIMETRES
TITLE
15
MATERIAL
DATE
PROJECTION
DRAWN BY
60
60
20

The dyeline process

Several methods are available for the production of photo-prints and by far the most popular is the dyeline process. This process depends on the behaviour of certain chemicals, which, before exposure to light combine with other chemicals to form a coloured dye. Should these chemicals be exposed to light this chemical reaction will not take place. This is known as photo-chemical effect. The dyeline paper is coated with light sensitive chemicals and to make a print the tracing is placed in close contact over a sheet of the dyeline paper and exposed to light. The light passes through the tracing material to the sensitized coating of the dyeline paper. The development is effected by the use of a liquid developer or by ammonia vapour; these are known as the semi-dry and the ammonia process respectively.

From the foregoing paragraph it will be evident that a tracing should possess a good *translucent quality* so that the photo-chemical effect or exposure takes place as quickly as possible, and the lines on the tracing material should be as dense as possible to prevent the light reaching the sensitized coating. However, should the lines be insufficiently dense to withhold the light the sensitized coating will be affected and the chemical reaction of the sensitized coating and the developer will be incomplete; the line on the print will not have the same intensity as if all the light had been withheld.

It will be readily appreciated that the speed of producing a dyeline print will be dependent on three factors: the transparency of the tracing material, the sensitivity of the sensitized coating, which will affect the speed at which the photo-chemical effect takes place, and the intensity of the light source.

The first condition is straight-forward. It is possible to select material with a fast or slow speed and it will be readily appreciated that the slower paper will require a longer exposure to complete the photo-chemical effect. It is not always desirable to use a fast material as the intensity of the developed line varies inversely as the speed of the paper: a slower paper will produce a stronger line and a faster paper a weaker line. The type of paper chosen will nearly always be dependent upon the equipment being used, i.e. the nature of the light source.

The nature of the light source is important as the sensitive coating of the paper responds to the light rays in the upper part of the spectrum only—the blue violet and ultra violet rays. The red, orange, yellow and green have little or no effect on it. It is for this reason that daylight is an excellent source of light as indeed are certain types of fluorescent tubes. Arc lamps and other light sources high in ultra violet content should be avoided because the intensity of the light is sufficient to damage permanently or destroy the retina. Ordinary filament lamps, which are deficient in actinic light rays, are unsuitable.

It will now be readily appreciated that any red, orange, yellow or green tinge in the tracing material will reduce the speed of printing: if, however, these colours are used in the lines on the tracing, the effective density of the line may be increased. Use is made of this principle in drawing office carbon paper.

Conversely, blue lines do not reproduce well, and the blue ink used for isometric grids and sectional tracing papers *will not reproduce*.

Materials

The majority of photo prints are made on paper of which there are several thicknesses available. Sensitized coatings may also be obtained on cartridge paper.

Development

The semi-dry method of development makes use of a liquid developer usually supplied in powder form and mixed with water. Only a very small amount of developer is necessary and the print may be moistened by lightly swabbing the surface with cotton wool moistened with developer. The developer may also be applied by passing the exposed material between rollers, the bottom roller revolving in the developer. This bottom roller transfers developer to the sensitized face of the paper.

Development by ammonia necessitates that the vapour or gas shall come into contact with the sensitized and exposed surface of the dyeline paper. Obviously this method is less suitable for schools, although its use may be necessary for the development of transparent materials. Small sheets may be successfully developed in a large sweet bottle containing a small receptacle of liquid ammonia.

Basic drawing techniques

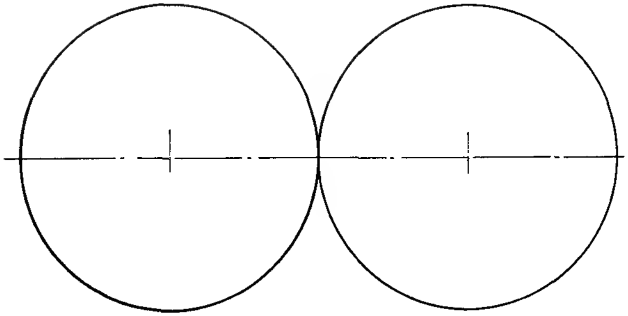
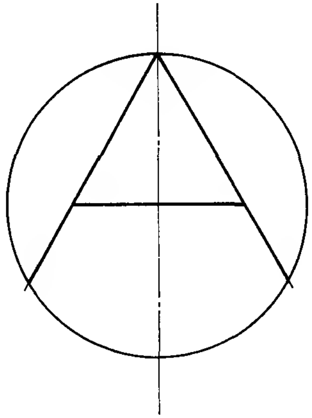
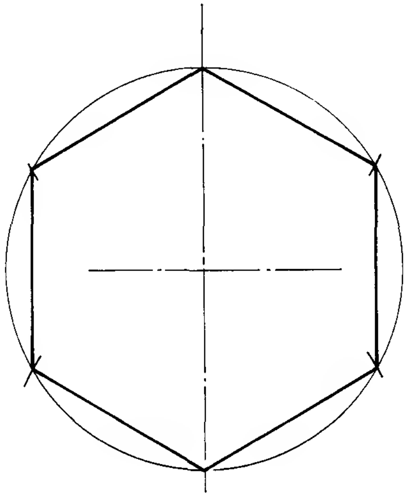
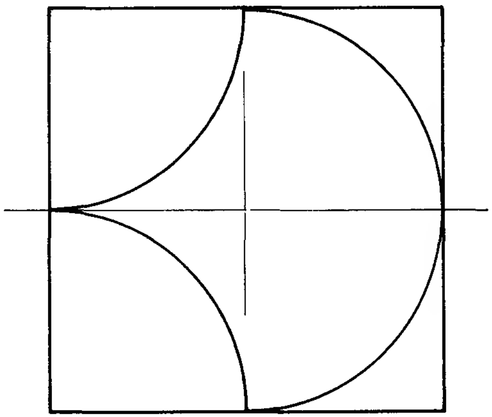
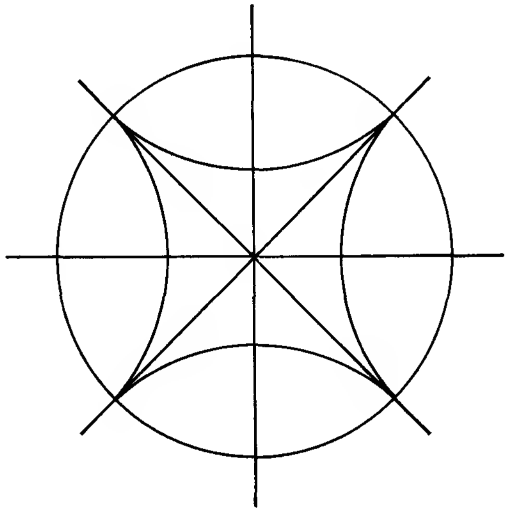
The following pages of examples, which may be familiar to many, may be used to develop a facility for the use of drawing instruments; an accurate execution is necessary if acceptable results are to be achieved.

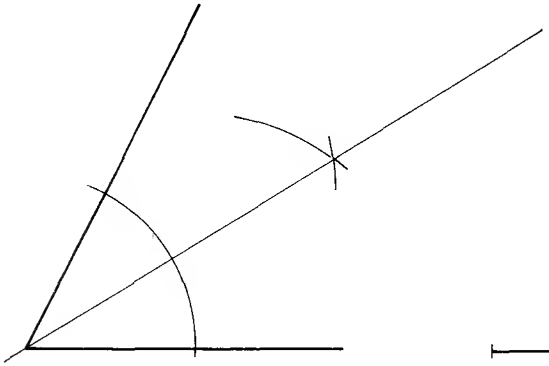
The examples on the first sheet are mainly concerned with compass work, requiring neat, crisp, accurate work; many more designs using a compass can be developed.

The examples on subsequent sheets are basic geometric constructions essential in all aspects of technical drawing. Not only do they afford good instrument practice but an understanding of and familiarity with fundamental techniques.

1. The bisection of an angle
2. The bisection of a line by a perpendicular bisector
3. The construction of a perpendicular through a point on a line
4. The construction of a perpendicular to a line from a point
5. The construction of a right-angle
6. The determination of the centre of an arc (the perpendicular bisectors of chords)
7. The division of a line into a number of equal parts
8. The circle and its parts
9. An arc within a right-angle
10. An arc within an acute angle
11. An arc within an obtuse angle
12. The construction of a regular hexagon, given the distance across the flats of the hexagon, and
13. given the length of a side
14. Regular octagons within a square, and
15. regular octagons within a circle
16. A circle inscribed within a triangle (two angles bisected)
17. A circle circumscribed around a triangle (two sides bisected)
18. An equilateral triangle with inscribed and circumscribed circles

(In this example either two angles or two sides or one of each may be bisected.)



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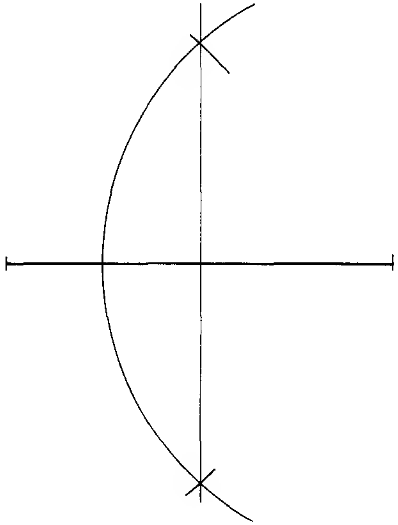

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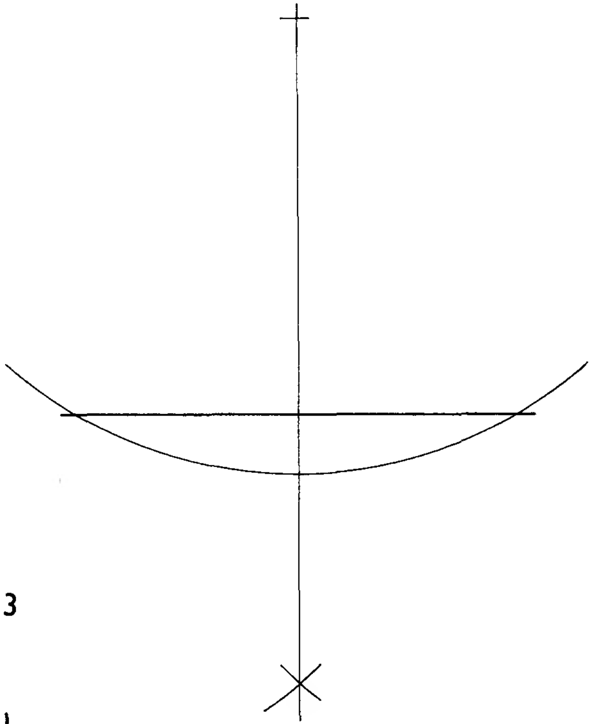

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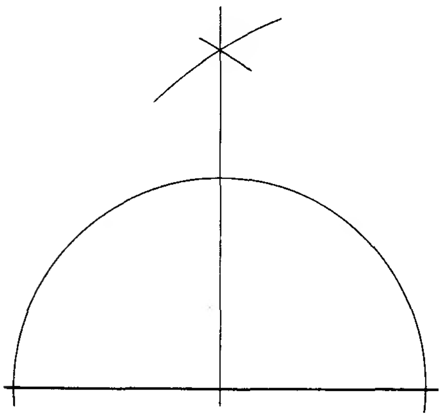

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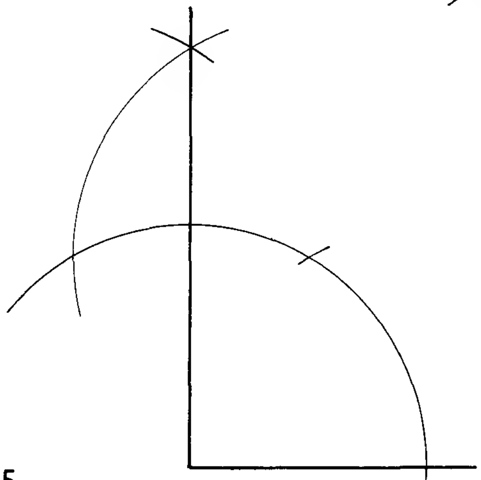

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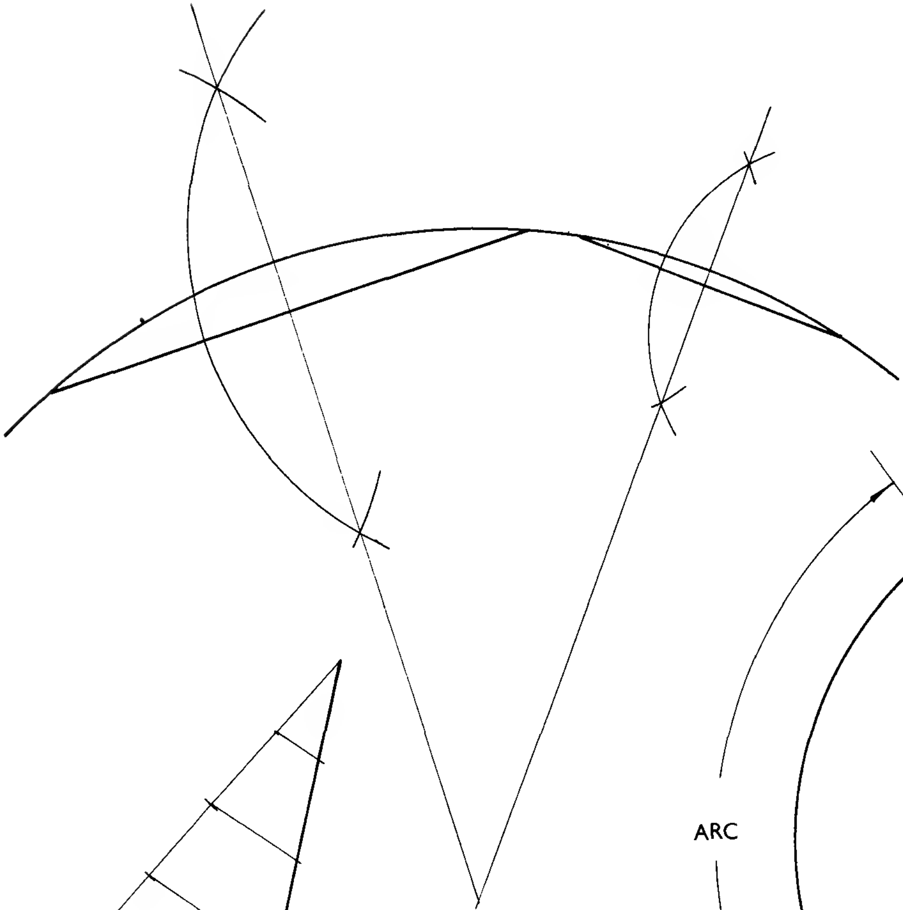

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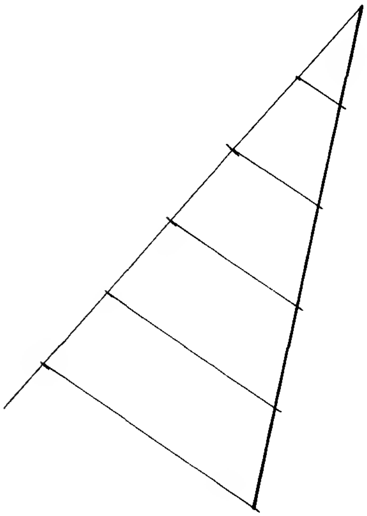

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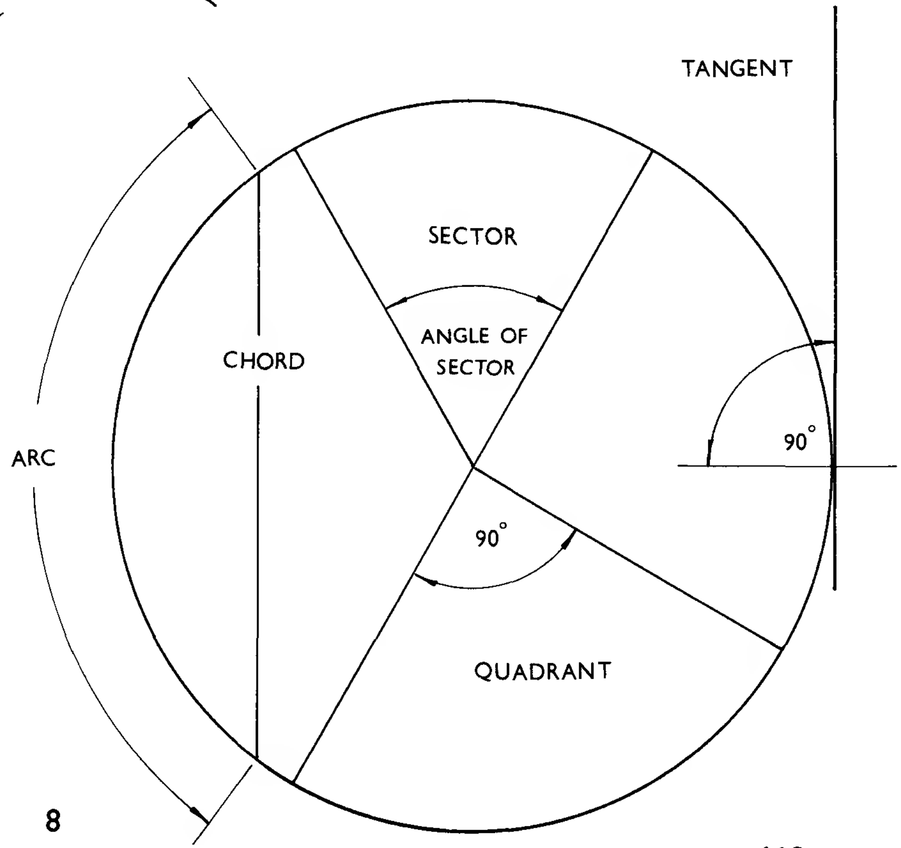

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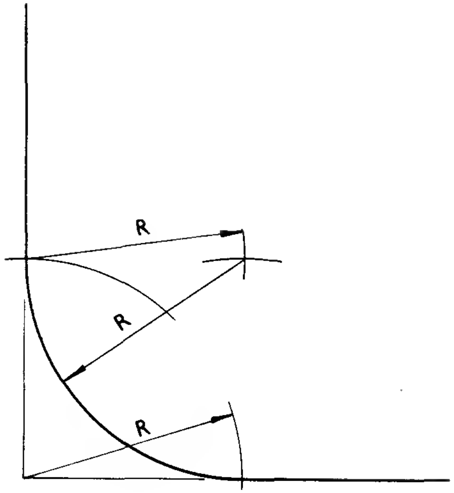

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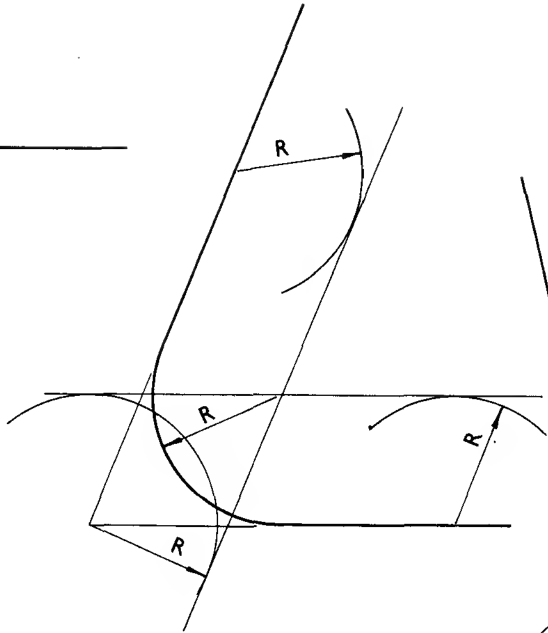

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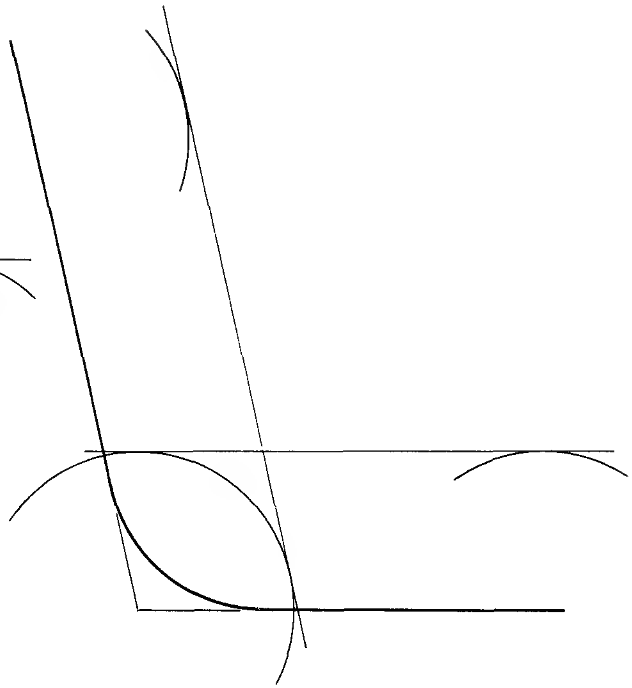

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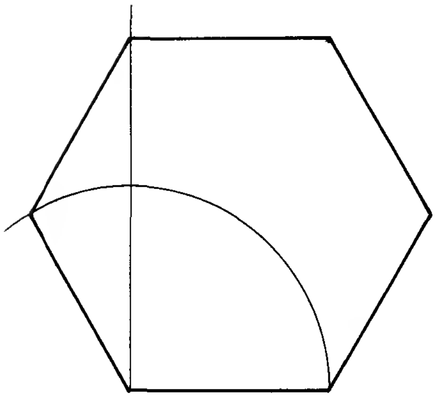

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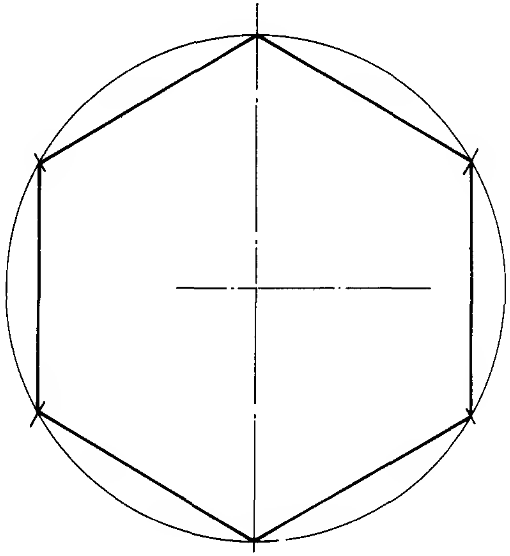

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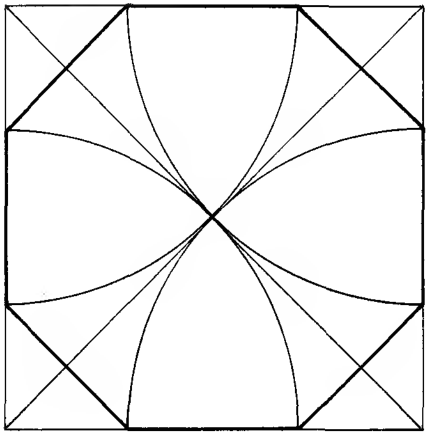

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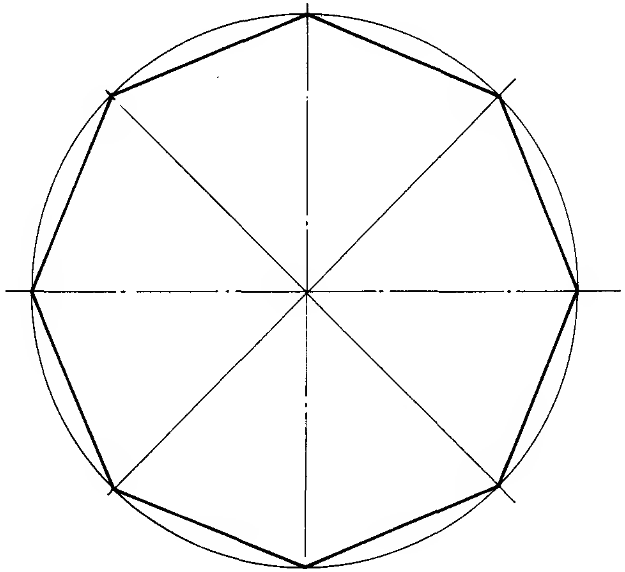

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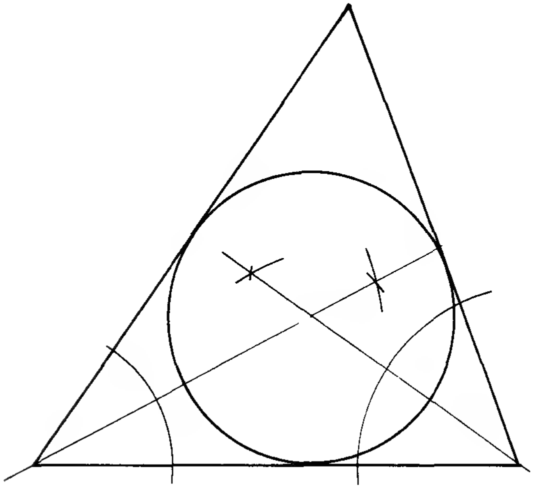

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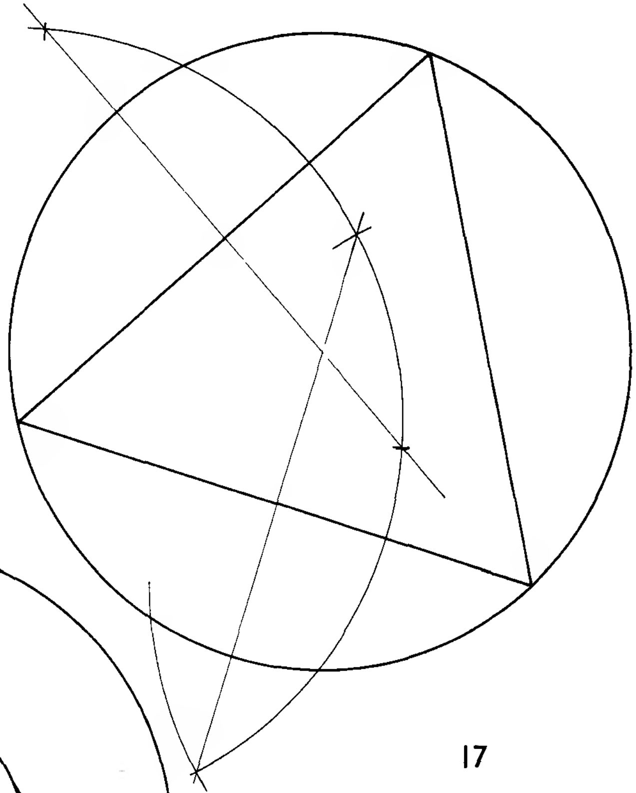

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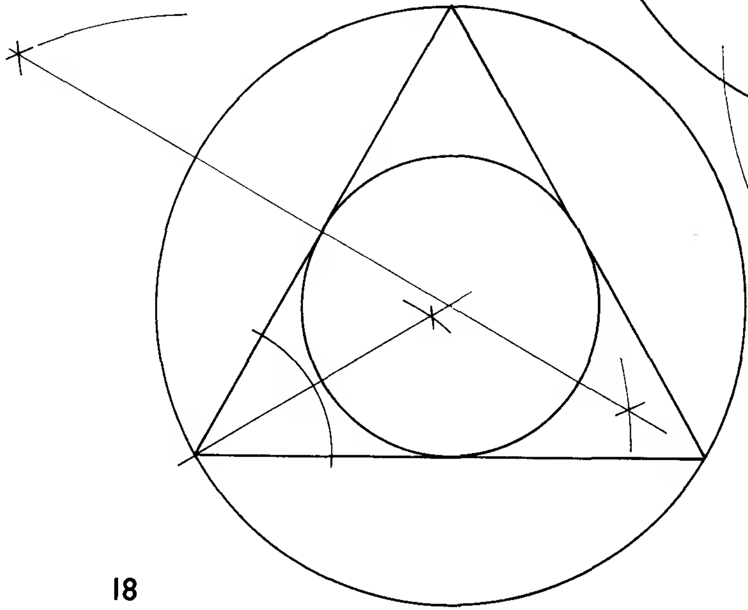


18

Materials

Ferrous metals

(Iron base metals)

Pig Iron

Pig iron is produced after reduction from the iron ore in the blast furnace. It is the base from which many kinds of iron and steel are made. It is of little use as it contains a high percentage of impurities which have to be removed by further processes.

Cast Iron

This metal is obtained from pig iron by smelting it in a cupola which is similar to a blast furnace but smaller. Some impurities in the pig iron are removed during this process. Cast iron is very brittle and easily broken. It has a very low tensile strength, but it can withstand considerable compressive forces. It consists essentially of iron with up to four per cent carbon, the carbon existing in both the chemical form and as free graphite. Cast iron is comparatively inexpensive and is mainly used for castings.

Chilled Cast Iron

When the surface of an iron casting is rapidly cooled, usually by *chills*, within the mould some of the carbon remains in a combined state. Chilled castings are therefore very hard on the surface.

White Cast Iron

This contains nearly all the carbon in the combined form and has a silvery-white appearance when fractured. It is very hard and brittle and impossible to machine.

Wrought Iron

Wrought iron is a soft, ductile, malleable and fatigue-resisting material. Wrought iron is less liable to fracture by impact than steel. It is used for such items as chains, crane hooks and electro-magnet cores. It can be case hardened.

Carbon Steels

Steel is basically an alloy of iron and carbon, the carbon existing in its chemical form only and not as free graphite. The maximum amount of carbon that can exist in this combined form is 1·7 per cent.

If carbon is present above 1·7 per cent, the metal begins to pass into the cast iron range as the carbon begins to come free or graphitic.

When other elements are added to the steel to impart certain properties, it is called alloy steel.

The plain carbon steels are usually classified as follows:
When the carbon content is less than 0·15 per cent, the steel is referred to as *dead mild*.
When the carbon content is between 0·15 per cent and 0·3 per cent the steel is referred to as *mild*, between 0·3 per cent and 0·8 per cent carbon, *medium carbon*, and when the carbon content is above 0·8 per cent the steel is referred to as *high carbon*.

Non-ferrous metals

(Metals whose base is other than iron)

Copper

Copper is a soft malleable ductile metal. It is an excellent conductor of heat and electricity, and is used for cables and other electrical work. It can be obtained in sheet, wire or bar form. Copper is readily soft or silver soldered, and will withstand considerable distortion without breaking. When it is being cold worked, it hardens fairly rapidly and needs annealing or softening between the various stages of the work.

Brass

Alloys of copper and zinc are called by the general name of brass. Brasses are harder and stronger than copper and can be machined more easily. Brass can be obtained in sheet, wire or bar form. Castings may also be made from brass. Soft and silver solders can be used on brass. Cold working hardens brass more quickly than copper, but it can be annealed between stages of the work. Brass is used for screws, terminals and small stampings. It resists corrosion well.

Bronze or Gun metal

These names are given to alloys of copper and tin and they are similar to brass but are harder and stronger. Generally bronze is more difficult to machine than brass. Its resistance to wear and corrosion, however, is greater. Bronze is produced in similar forms to those of brass and its heat treatment is also similar.

Phosphor Bronze

This is an alloy of copper and tin containing also a small percentage of phosphorous. Phosphor bronze is used extensively for bearings.

Aluminium

Pure aluminium is very rarely used because it is so soft and has little strength. Aluminium is an excellent conductor of electricity. Many alloys with other metals are used for special purposes, but in most work it can usually be accepted that the metal is an alloy of aluminium and copper. These alloys can be obtained in all the sizes and sections that are used for brass. There is no satisfactory method of soldering aluminium because of a very refractory oxide which quickly forms on the surface. This film renders the metal very resistant to ordinary atmospheric corrosion, but when it is exposed to the action of many common substances, like common salt, it rapidly corrodes. Its resistance to corrosion is improved by anodizing, which is an electrolytic process.

Aluminium can be welded satisfactorily, but considerable experience is necessary before successful results are achieved.

White Metal Alloys

These are alloys of low melting point having either zinc, lead or tin as the major element, referred to as the *base* of an alloy.

Zinc based alloys are used chiefly for pressure die castings, for example, carburettors and small machine parts.

Tin based alloys are known as Babbit metals and are used for bearings where high speeds and heavy loads are encountered.

Lead based alloys are softer than the Babbit metals and are used for high speed bearings which are working under lighter loads.

Fusible Alloys

These are low melting point alloys produced by a combination of bismuth, lead, tin and cadmium, for example, Rose's Alloy, Wood's Metal and Lipowitz's Alloy.

Processes

Hardening and Tempering

Many small hand tools, such as scribers and screwdrivers, have to be hard enough to mark metals and drive screws into position without becoming damaged. If the metal is as hard as this it is difficult to make the tool. Tool steels can be shaped and then hardened but usually the resulting brittleness makes them unsuitable for many purposes. The process of softening sufficiently to make the tool suitable for a particular purpose is called tempering.

A plain carbon tool steel is hardened by heating it to a *cherry red heat* and then quenching it in water or oil. Hardening will not take place until a definite temperature has been reached; this is known as the *upper critical temperature*. For ordinary tool steels a cherry red heat is sufficient to achieve full hardening. Retention at a temperature much in excess of this critical temperature will impair the strength of the steel and the hardness will also be reduced. After hardening, the steel is polished and heated gently, when the surface will show a series of colour changes, owing to the thickness of the oxide film. The first colour to appear is light straw, gradually turning to brown-purple and blue; these colour changes indicate the degree of softening which has taken place. When the tool has been sufficiently softened it is quenched in water or oil. Quenching in water gives a harder product than quenching in oil, but tools which are complicated in shape are less likely to develop cracks if they are quenched in oil.

Case-hardening

It is often necessary for a piece of work to be hard on the outside to resist wear, and at the same time it may be required to resist shock loading.

These two conditions can only exist if the material is hard on the outside whilst the inside remains tough. Normal heat treatment by hardening and tempering a plain carbon steel does not produce the desired effect. A hard surface on a soft core may be achieved by a case or surface hardening process.

Pack or Box Hardening

This process, given to low carbon steels, is carried out by heating a mild steel component in contact with a material rich in carbon. The carbon is absorbed by the outer layers of the steel. The process is carried out in four parts:

1. Carburising
2. Slow cooling annealing
3. Refining or normalizing the core
4. Hardening—followed by tempering if required.

The parts to be heated are packed in boxes made of heat-resisting alloy, an alloy containing a high percentage of nickel and chromium, with a carbon rich material, usually one of the proprietary case-hardening compounds, and heated to a temperature in excess of the upper critical temperature for several hours.

A twelve hour period will give a penetration of 2·5 millimetres, whilst three hours will give a depth of case about 1 millimetre. After this period the box is removed from the furnace and allowed to cool. Cooling slowly anneals the carbon case. It will be necessary to normalize or refine the core of the component, as retention at a high temperature will have promoted grain growth: this will necessitate re-heating the component after it has been removed from the box, to 900°–950°C. The component is then allowed to cool slowly; in practice, however, the components are usually quenched in oil.

The process of carburising has given the component a high carbon skin or case which can be hardened by heating to 800°C and then quenched in either water or oil. The case may be further heat treated by tempering.

Parts of the surface that are to remain soft should be coated with copper or packed in clay before the process is commenced.

Methods of joining materials

Rivets, screws, nuts and bolts are considered temporary methods of joining materials and *soldering* is regarded as a permanent method.

Rivets

These are described by diameter, length and shape of the head, and are made from all the common non-ferrous metals and mild steel.

Pop-rivets

These are of tubular form and may be obtained in steel, copper and aluminium. The smaller diameter rivets may be applied with special pliers; the larger sizes call for more expensive equipment. (The head of a centre pin is drawn through the rivet causing that portion of the rivet which protrudes from the back surface to swell until the head of the pin is broken off in tension.)

Screws

These are described by diameter, type of thread, length and shape of head, and by the material of which they are made, usually mild steel or brass. Screws are threaded for their entire length; bolts are only partially threaded. They are described in the same way as screws.

Parker Kaylon self-tapping screws

These hardened screws are intended for the joining of sheet metal not usually thicker than 16SWG (1·5 mm or ·062 in.). The tapping hole is drilled or punched and the screws are so hardened and threaded that it is possible for them to cut a thread in the metal as they are screwed in.

The form of the head may be countersunk, round, raised, pan or mushroom head and the diameter is indicated by gauge: No. 2; No. 4; No. 6; No. 8; No. 10; No. 12; No. 14 (No. 2 is approximately 2 mm diameter and No. 14 is approximately 6 mm diameter). These screws may be obtained in the natural colour or plated in nickel, brass, copper, cadmium and zinc in the more popular sizes.

Except in the case of the pan head it is possible to obtain these screws with the Phillips recessed head, and this is often to be preferred as it is possible to obtain a more positive drive.

Locking Devices

When nuts and bolts are subjected to rapid vibration or axial load or to both conditions at the same time, there is a tendency for the nut to work loose and it is sometimes necessary to use a locking device. The locking devices mentioned below are the most common in general use.

Locked nuts

To use an additional thinner nut is the most common method of nut locking. The upper nut which is supporting the load should be of normal thickness; the lower one which is locking it may be thinner. In practice, however, the reverse is often the case because of the necessity to use a thin spanner for the bottom nut.

Castle nut

This is a simple and effective locking nut; slight adjustment, one sixth of a turn, is possible.

Spring washers

These are frequently used and give thrust to the nut. Washers with a single coil are called Grover washers and those of the double coil are called Thackray washers. It is important to notice the handing of the coil and the effect of the end corners in tending to prevent the nut unscrewing.

Tab or safety washer

These washers are usually made of mild steel, copper or brass. One tab is bent up against the face of the nut; the other is bent over the edge of the component.

There are also very many special patent devices which are quick to use and effective in their action and of these the following readily suggest themselves:

Simmonds nut

This nut has a fibre insert which bites into the thread of the screw or bolt.

Star washers

These also fall into this category.

Screw threads

There are several standard forms of thread, each suitable for a particular purpose. For most screws used in radio, electrical and instrument work the British Association thread is used. For model engineering there are special taps and dies for producing very fine threads. There are also cycle threads, pipe threads, conduit threads and brass threads. In brass the threads per inch are the same for all sizes, namely 26. For constructional steel work the Whitworth standard is used (BSW). Bolts using the Whitworth form of thread can be obtained from $\frac{1}{8}$ in. to very large sizes. The Whitworth standard threads are rather coarse, and for many purposes the British Standard Fine (BSF) is to be preferred; it is widely used in the engineering industry. The range of sizes is the same as the Whitworth standard form, from $\frac{7}{32}$ in. upwards.

An important step forward in the standardisation of screw threads has been brought about by agreement between British, American and Canadian interests, with the advent of the "unified" thread. The unified thread form is essentially the same as the American national thread form, the thread form being 60° in both cases. They can be obtained in two grades, unified national coarse (UNC) and unified national fine (UNF). The spanners for unified thread series are the American A/F sizes. (A/F. . . . distance across the flats of the hexagon).

In recent years a major change of screw thread forms has become necessary.

The President of the Board of Trade announced in parliament, on 24th May, 1965, that British Industry should progressively adopt metric units until that system became the standard system of weights and measures for the United Kingdom.

This statement led to a conference, organized by the British Standards Institute, at which the major sectors of British Industry were represented. The conference approved a policy which renders obsolescent the present British traditional screw thread systems of Whitworth, British Association and British Standard Fine and approves the supersession of these forms of screw thread by the internationally agreed ISO metric thread form. These recommendations of the ISO (International Organisation for Standardisation), for bolts, screws and nut dimensions, have been published in a revised edition of BS 3692, 1967. This reorganisation will lead to the universal standardisation of screw threads. Meanwhile the variety of screw thread forms will diminish.

The ISO metric coarse threads will, in most cases, be found to be satisfactory. The ISO metric series of fine threads are finer than both those in the UNF series and the British Standard Fine threads. It should not be assumed that the ISO metric fine are a substitute for these thread forms.

Standard diameters

Table A shows the nearest recommended metric diameters to replace inch diameters. M is the official ISO recommended symbol for ISO metric threads.

Figures in brackets are the decimal inch equivalents. The complete range of ISO metric bolts, screws and nuts will be from M1.6 to M68.

Comparison of Inch and Metric Threads

Table B gives a detailed comparison.

Complete details of ISO metric bolts, screws and nuts may be found in BS 3692 1967.

Table A. Standard diameters

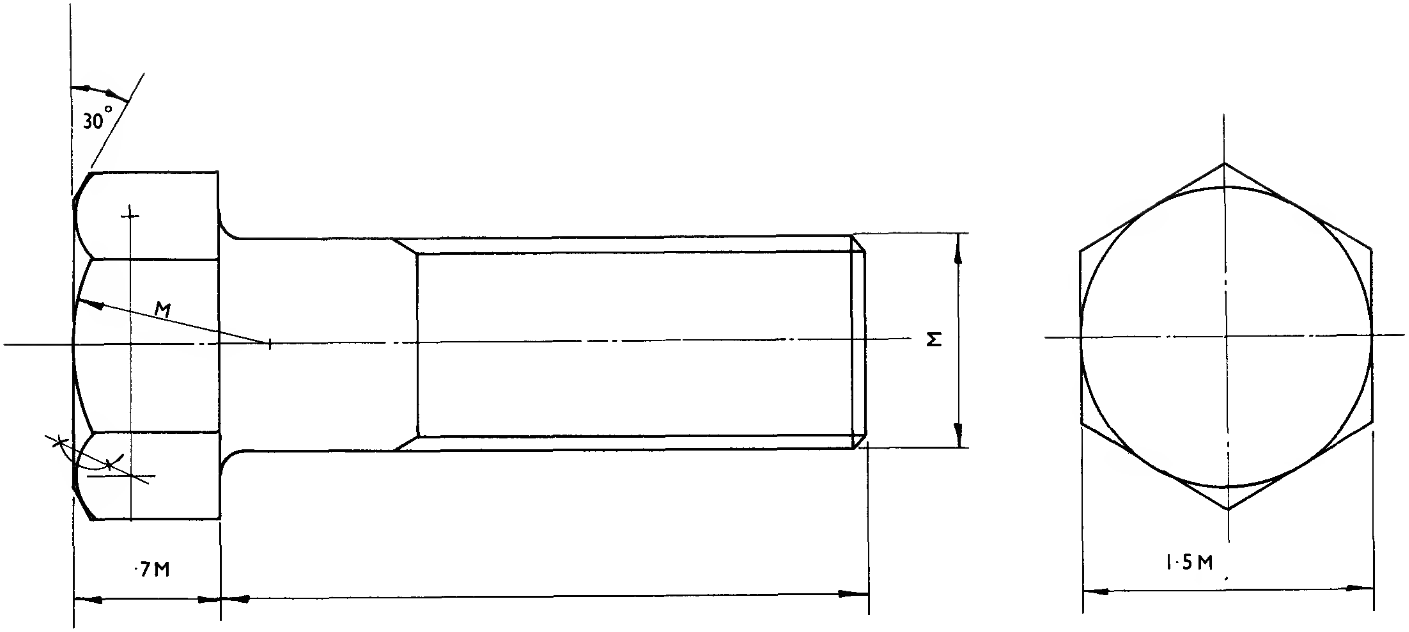
Metric Dia	Pitch of the Thread (mm) (Coarse Pitch Series)
M 1.6 (0.063″)	0.35
M 2 (0.078″)	0.4
M 2.5 (0.098″)	0.45
M 3 (0.118″)	0.5
M 4 (0.157″)	0.7
M 5 (0.197″)	0.8
M 6 (0.236″)	1
M 8 (0.315″)	1.25

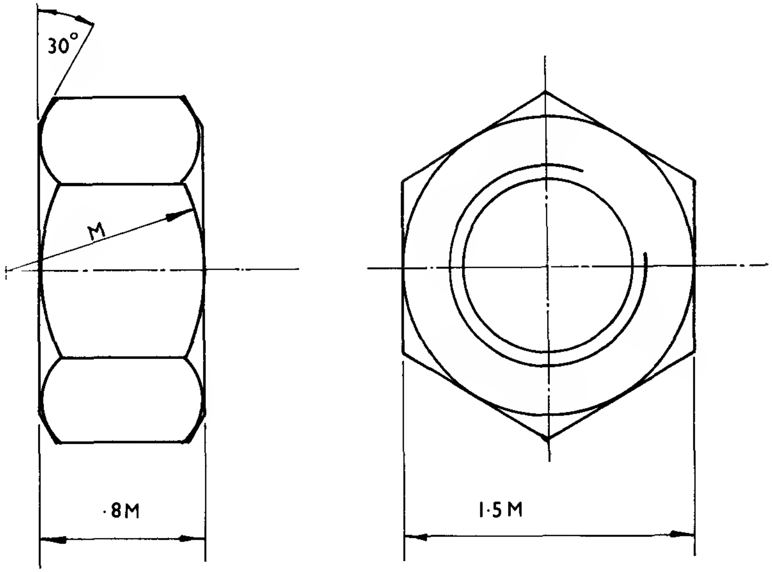
Metric Dia	Pitch of the Thread (mm) (Coarse Pitch Series)
M10 (0.394″)	1.5
M12 (0.472″)	1.75
*M14 (0.551″)	2
M16 (0.630″)	2
M20 (0.787″)	2.5
*M22 (0.866″)	2.5
M24 (0.945″)	3

*These are non-preferred diameters and should be avoided.

Table B. Comparison of Inch and Metric Threads

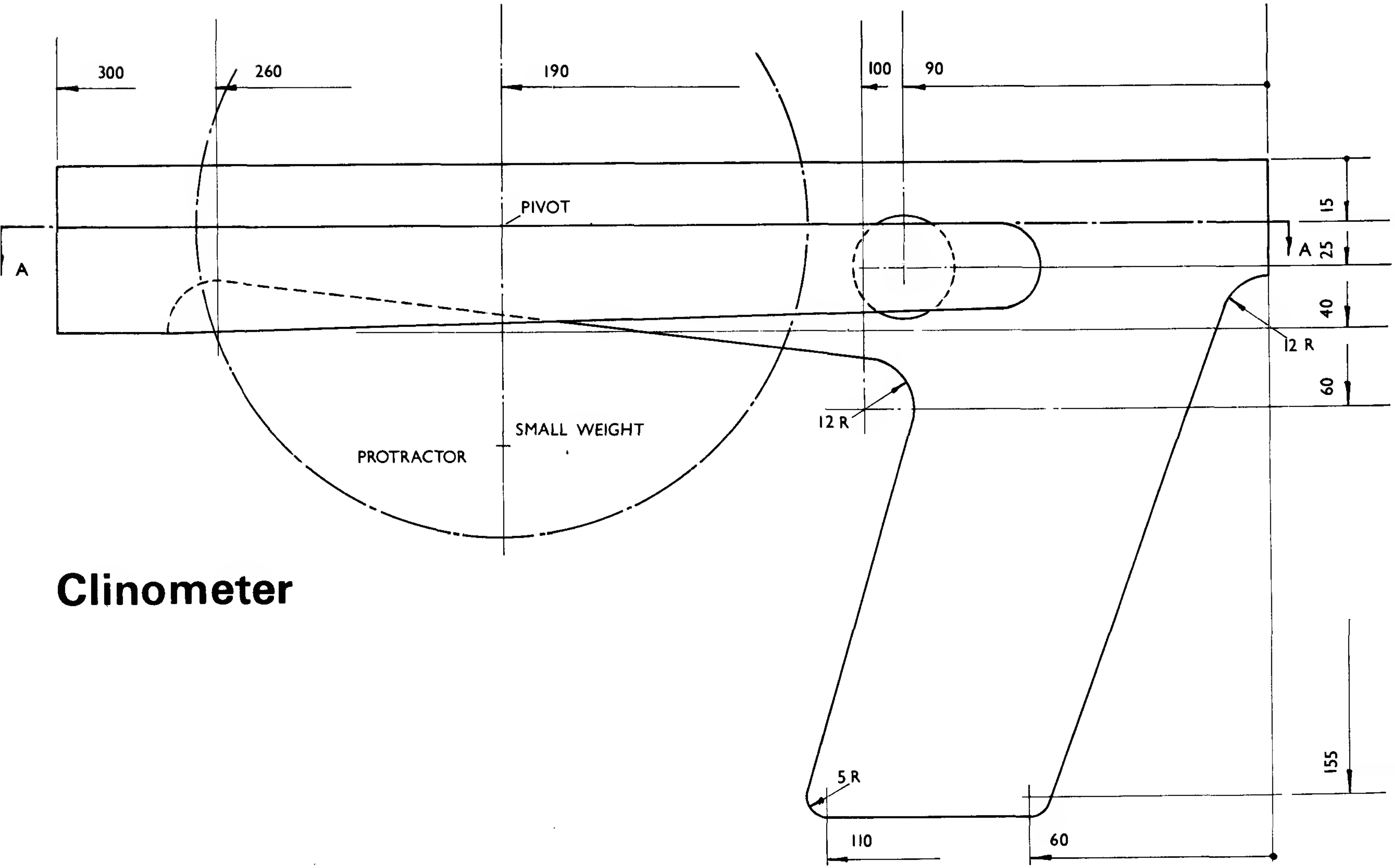
Dia	BS Whitworth TPI	BS Fine TPI	ISO Metric Coarse Dia	ISO Metric Coarse TPI (Approx)	ISO Metric Fine	UN Coarse TPI	UN Fine TPI
$\frac{1}{4}$″ (0.250″)	20	26	6mm (0.236″)	25.4	ISO metric fine threads are finer than in the UN fine series and much finer than BS Fine threads. ISO metric coarse threads will, in most cases, be a suitable substitute for BS Fine, BS Whitworth and BA threads.	20	28
$\frac{5}{16}$″ (0.3125″)	18	22	8mm (0.315″)	20.3		18	24
$\frac{3}{8}$″ (0.375″)	16	20	10mm (0.394″)	17.0		16	24
$\frac{7}{16}$″ (0.4375″)	14	18	12mm (0.472″)	14.5		14	20
$\frac{1}{2}$″ (0.500″)	12	16				13	20
$\frac{5}{8}$″ (0.625″)	11	14	16mm (0.630″)	12.7		11	18
$\frac{3}{4}$″ (0.750″)	10	12	20mm (0.787″)	10.1		10	16
1″ (1.000″)	8	10	24mm (0.945″)	8.5		8	12





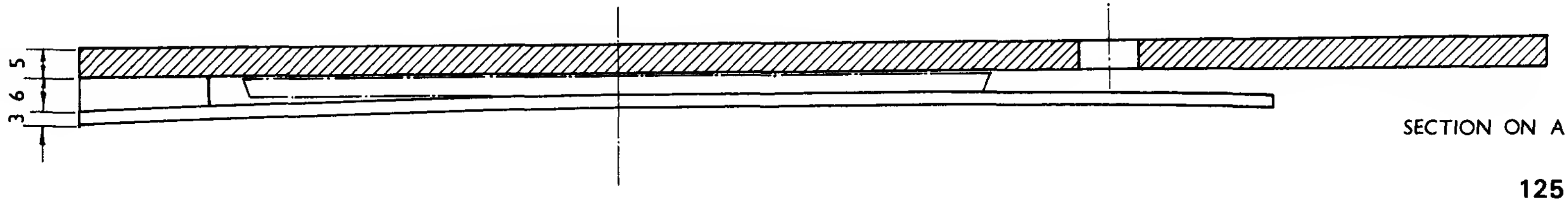
This drawing shows the basic drafting dimensions that may be used to represent ISO metric hexagon bolts, screws and nuts. Precise dimensions may be found in BS 3692, 1967.

The arcs on the heads of the bolts and on the nuts may be drawn as shown using a spring bow; alternatively, a set of radius curves may be used.



Clinometer

DIMENSIONS IN MILLIMETRES



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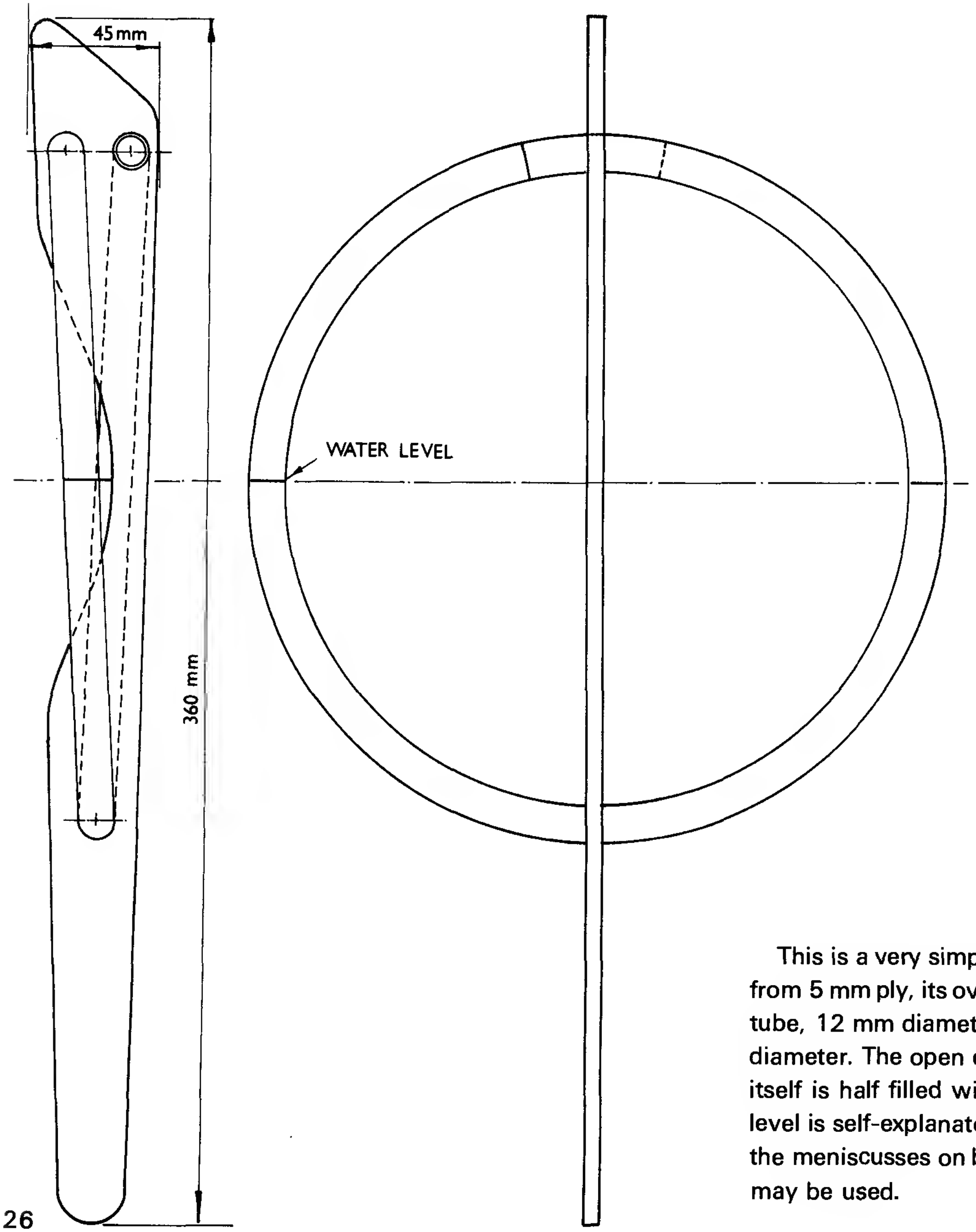
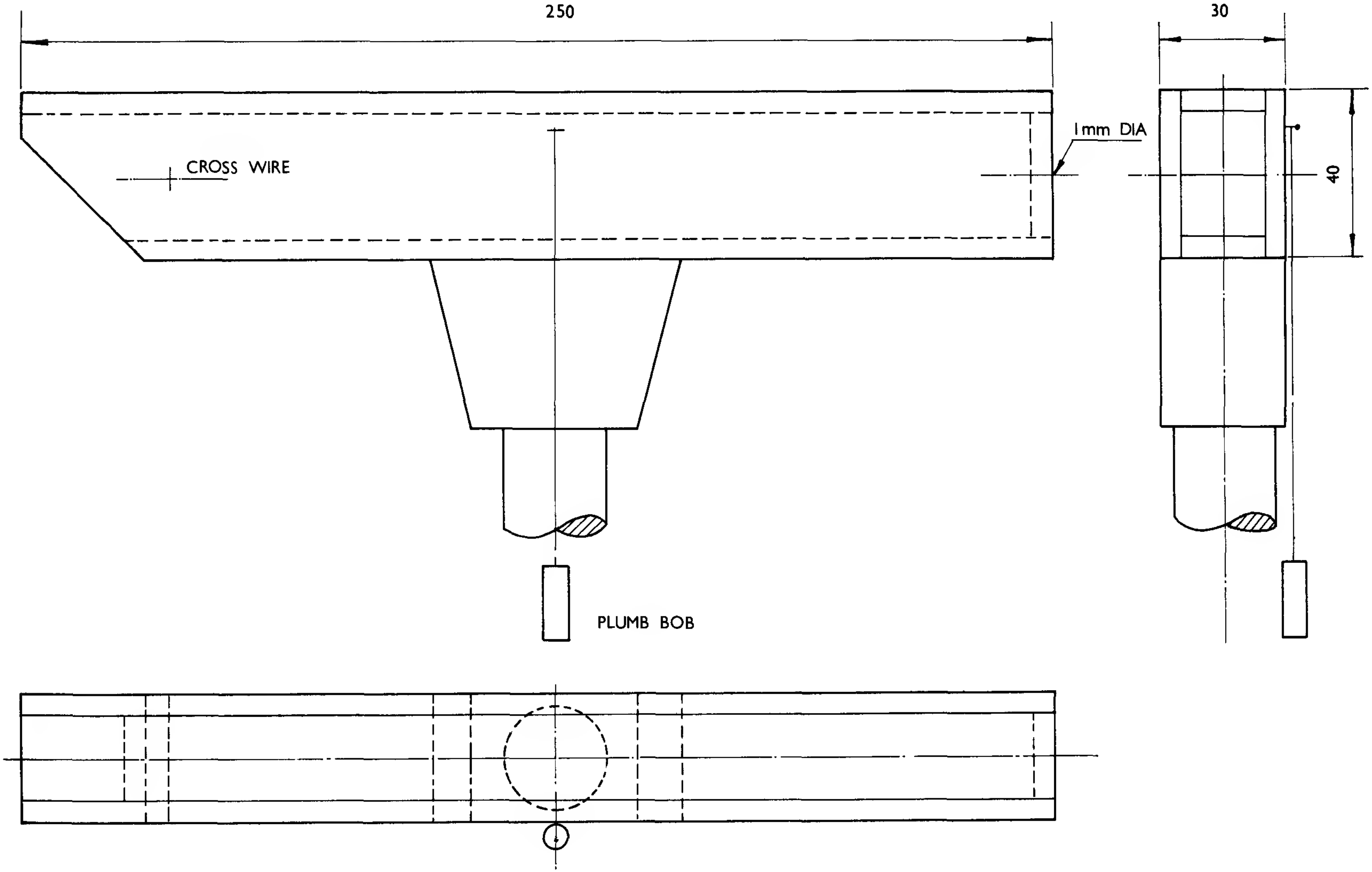
Level

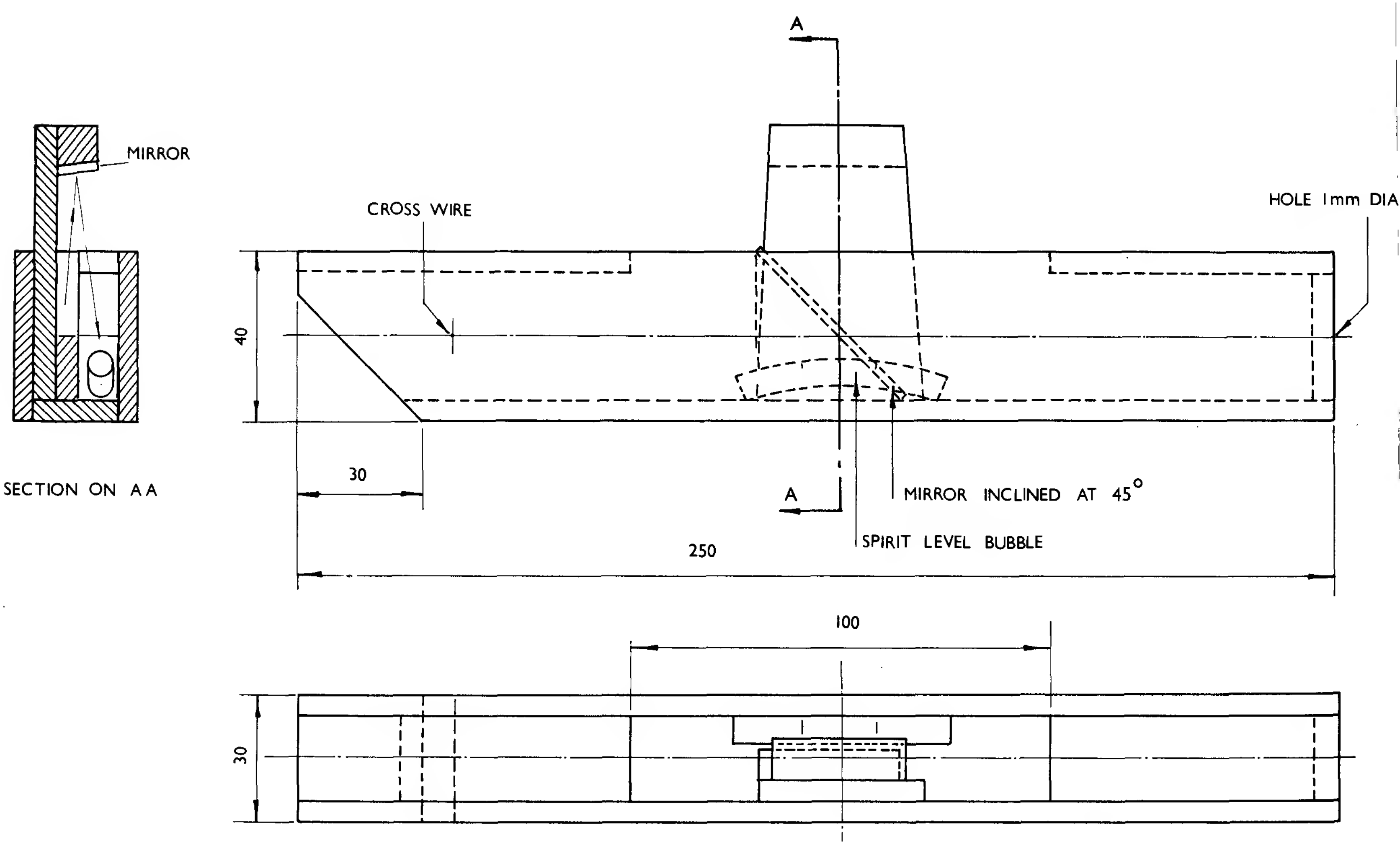


This is a very simple level; it is in fact a simple U tube. Made from 5 mm ply, its overall length is 360 mm and the clear plastic tube, 12 mm diameter, is formed into a circle about 200 mm in diameter. The open ends of the tube are at the top and the tube itself is half filled with water. The method of using this simple level is self-explanatory. Should difficulty arise in distinguishing the meniscusses on both sides of the tube, small coloured floats may be used.



HAND LEVEL 1

DIMENSIONS IN MILLIMETRES



HAND LEVEL 2

DIMENSIONS IN MILLIMETRES

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